ON THE

ORIGIN OF THE PARALLEL ROADS OF LOCHABER

AND THEIR BEARING ON

OTHER PHENOMENA OF THE GLACIAL PERIOD.

BY

JOSEPH PRESTWICH, M.A., F.R.S., F.G.S., &c.,

PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF OXFORD.

From the PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY.—PART II. 1879.

With the author's
best regards
March 22. 1880!
J. F. Campbell
Niddry Lodge
Kensington
W.

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XVII. *On the Origin of the Parallel Roads of Lochaber and their Bearing on other Phenomena of the Glacial Period.*

By Joseph Prestwich, *M.A., F.R.S., F.G.S., &c., Professor of Geology in the University of Oxford.*

Received March 27,—Read May 1, 1879.

[Plate 46.]

Contents.

State of the Question.

It is now forty years since the origin of the parallel roads of Lochaber was discussed before the Royal Society by Darwin,* in his well-known paper on the subject; but, although the problem had been for some time previously, and has since continued to be, the subject elsewhere of many communications, considerable difference of opinion

* Philosophical Transactions for 1839, p. 39.

still exists on some of the theoretical questions.* The main physical features have, however, been so carefully and well noted, that they may now mostly be taken as admitted.

In explanation of the general problem, I accept the lake theory of MACCULLOCH and DICK-LAUDER, and the glacial theory of AGASSIZ. I cannot, however, agree with the expositions of those theories, whether in respect to the mode of formation of the "roads," or in regard to the precise age of the lakes, which have been of late years very generally held. I therefore desire to place before the Society my grounds of dissent, and to submit the views which I have been led to form by a visit made last summer to the remarkable district of Lochaber and from the general consideration of the subject. I will first briefly notice the various theories that have been previously advanced, and mention what, as it appears to me, are the objections to them.

§ 1. *The Detrital and Marine Theories.*

The masterly papers of MACCULLOCH† in 1817, and of Sir T. DICK-LAUDER‡ in 1818, gave reasons to show that the parallel roads in Glen Roy were due to lake action; but, while coming to this conclusion, they both felt the great difficulty, in the then state of our knowledge, of conceiving by what means the lakes could have been dammed up. MACCULLOCH conjectured some form of detrital barriers as a possible cause, but could suggest no adequate agency either for the origin or removal of such barriers.

In 1847, Mr. DAVID MILNE HOME, after a special examination of the superficial deposits of the district, proposed an explanation for the barriers on the "*detrital theory*," of which he has since been the consistent advocate.§ To account for their formation as well as for their removal, he supposes that after the period of the first great glaciation of Scotland the land was "submerged to the extent of 3,000 feet or more," and that during this submergence, or as the sea retired, "beds of clay, sand, and gravel, and also erratic boulders were deposited" by currents from the W.N.W. and N.W.; and he points to the large accumulation of such detritus in the valleys, and the common occurrence of detached portions and isolated masses, together with a general sprinkling of similar detritus, on the hill slopes at elevations above that of the highest of the "parallel roads," in support of his views. He considers "it manifest that all this district was formerly covered by detritus to 2,000 feet above the sea, and that it filled

* They have been well summarised by CHAMBERS, in 'Ancient Sea Margins,' p. 95, 1848; by JAMIESON, in 1863 (*post*); by Sir CHARLES LYELL, in 'The Antiquity of Man,' 4th edit., p. 300, 1873; by Dr. JAMES GEIKIE in 'The Great Ice Age,' 2nd edit., p. 227, 1877; by Professor TYNDALL, in Proc. Roy. Inst. Gt. Britain for June, 1876; and by other writers; while the admirable maps of the Ordnance Survey now give the accurate heights and the exact range of the "roads," which are further described and illustrated by the late Sir H. JAMES in 'Notes on the Parallel Roads of Glen Roy,' Ordnance Office, 1874.

† Trans. Geol. Soc. of London, vol. iv., p. 314.

‡ Trans. Royal Soc. Edinburgh, vol. ix., p. 1.

§ See his exhaustive memoirs "On the Parallel Roads of Lochaber," Trans. Royal Soc. Edinburgh, vol. xvi., p. 395, 1847: vol. xxvii., p. 595, 1876; and vol. xxviii., p. 93, 1877.

the Great Glen." He meets the difficulty as to the efficiency of a dam entirely detrital, by supposing that the lakes might have been formed while the sea still stood at the height of 500 to 600 feet higher than at present, that the rivers ran in higher channels, and that the valleys had been deepened since that period.

In opposition to these views, it is contended that the erratic boulders have been transported by land ice, and supposing even the possibility of a detrital accumulation by sea action sufficient to block the several lake-glens, how, it is asked, could it have escaped filling up Loch Lochy and Loch Linnhe; while any denuding force that could possibly have again excavated these deep depressions, could hardly have failed to remove the intervening barriers which separate the several lochs in the Great Glen.

Nor, supposing that barriers such as Mr. MILNE HOME describes had existed, do I imagine they could have formed impermeable dams to any large bodies of water. It might be possible for tenacious moraine clay or Till to form impervious barriers, but stratified beds of loose "gravel, sand, and clay" formed by marine currents could not possibly be water-tight. Had even the sea outside tended to stand as high as the lake, though the level of those inner waters might have been maintained some few feet higher, still as the land rose, and the sea-level gradually fell, so would the surface of the lakes subside by percolation, and their height would be regulated by that of the sea-level, and not, as they evidently have been, by the height of the several cols.

Mr. MILNE HOME suggests that the lakes need not have been very deep—that the glens themselves were so obstructed with detritus as to reduce their depth to 100 feet. If so, it is not easy to see how the upper end of Glen Roy could be so comparatively free from detritus, and yet so large an accumulation of moraine matter and gravel remain in its lower end, below its junction with Glen Glaster, where the scouring action of the outflowing water must have been greater.

The argument that the valleys may have been subsequently deepened is disproved by the fact that, with the exception of the narrow river-cut channel, the valley floors remain as when left after the previous general glaciation, glaciated rocks showing everywhere in the bed of the valley of Glen Spean, and in places in Glen Roy.

The "*marine theory*," which regards the "roads" as old sea beaches, was briefly alluded to by MACCULLOCH. It was afterwards brought forward with his usual power of illustration, but subsequently abandoned, by DARWIN. It had an able supporter in the late Dr. R. CHAMBERS, and has more recently found strenuous advocates in Professor NICOL* and Mr. J. F. CAMPBELL.† The manifest objection to this theory is the difficulty to conceive beaches to have been formed in glens such as those of the Roy and the Spean, without similar beaches having been formed in the adjacent valleys; and that on this hypothesis the terrace in Glen Gluoy should be on the level of the upper terrace of Glen Roy, whereas there is a difference of 18 feet between them. The whole of the "roads" ought at least to have been common to the three glens, where the conditions

* Quart. Journ. Geol. Soc., vol. xxv., p. 283, 1869.

† 'The Parallel Roads of Lochaber,' privately printed, November, 1877.

are alike. The advocates of the "marine theory" point to the worn and rounded detrital materials, to the beds of sand and the boulders before alluded to, and to the numerous local gravel terraces throughout Scotland as evidence of marine agency, but their number, their limited range and differences of level, point to the operation of independent local causes rather than to an uniform general cause such as a sea level. The phenomena admits also of explanation by land waters and other causes to be mentioned hereafter. Professor NICOL'S* answer relative to the coincidence of the "road" levels with those of successive cols, which he explains by checked tidal currents, cannot be considered satisfactory. The improbability, amounting almost to impossibility, of a series of such coincidences as a period of rest concurring with the level of each col during the general emergence of the land must be apparent.

Further, the fact that nowhere have marine organisms been found in the drift ascribed to marine origin, has been urged as an argument against the marine hypothesis. It is true that, in loose sand and gravel, shells may have been dissolved out by the percolation of water; but considering the extent of the débris, the many sections, and the occasional presence of argillaceous seams, it is difficult to understand their absence everywhere. It must, nevertheless, be borne in mind that even in those low levels, which there is every reason to suppose have been submerged, marine remains are very rare (postea, p. 691).†

Mr. MILNE HOME does, however, in a later paper, refer to two finds of shells,—one on the top of Unachan Hill, and the other in a field near Spean Bridge. But the specimens were not seen by him. In both instances they were found near the surface, and directly under the peat, and from the way in which his informant speaks of them, I should judge that they were recent shells by chance buried there.‡

§ 2. *The Glacial Theory of* AGASSIZ : *Mr.* JAMIESON'S *Exposition.*

AGASSIZ and BUCKLAND, who visited Scotland together in 1840, came to the conclusion that with respect to the "parallel roads" of Lochaber "the glacial theory alone satisfied all the exigencies of the phenomena."§ AGASSIZ suggested that a glacier, "issuing from the valley of Loch Arkaig, crossing Loch Lochy, and damming up Glen Gluoy below Low Bridge," would explain the origin of the lake and highest "road" in Glen Gluoy. A second great glacier descending from Ben Nevis, crossing

* Quart. Journ. Geol. Soc., vol. xxviii., p. 237, 1872.

† Sir T. DICK-LAUDER, speaking of the long and deep cuttings of the Caledonian Canal, says that "after cutting through a thick stratum of moss, nothing but sand, clay, gravel, and rounded stones were found . . . . nor has the slightest appearance of marine exuviæ been anywhere discovered."—*Op. cit.*, p. 27. DARWIN, however, states that he was informed that broken sea-shells were found in the lower part of the gravel at the head of Loch Ness, at a point about 40 to 50 feet above the level of the sea.—Phil. Trans. for 1839, p. 57.

‡ Trans. Roy. Soc. Edinb., vol. xxviii., p. 116, 1877.

§ "The Glacial Theory and its recent Progress." By LOUIS AGASSIZ.—Edin. New Phil. Journ., vol. xxxiii., p. 236, 1842.

the Spean, and resting on Moeldhu which is opposite, shut up the lower end of Strath Spean; while a third glacier issued from Glen Treig, and barred the valley of the Spean higher up. The last two glaciers served as barriers to the Glen Roy lakes, all of which he considered had extended into the opposite part of Glen Spean. On the retreat of the glacier of Glen Treig, the lake-waters were lowered, and, spreading into upper Glen Spean, escaped eastward through Glen Spey. In proof of the existence of this glacier, AGASSIZ pointed out that the striæ on the rocks in Glen Spean, opposite Glen Treig, were parallel with the axis of Glen Treig and transverse to the direction of Strath Spean. But his allusion to the phenomena of the parallel roads was incidental to the general question, and the subject was not discussed in detail.

Adopting the glacial theory and general views of AGASSIZ, Mr. JAMIESON, in 1863, with an intimate knowledge of the drift phenomena of the north of Scotland, sought, in a further investigation of the district, for the more special conditions applicable to this particular case.*

Scotch geologists had in the meantime come to the opinion that the first great glaciation of the country had been succeeded by a warm interglacial period, which was followed by another period of considerable cold, during which only local glaciers descended from the greater mountain ranges.

Mr. JAMIESON concluded (although apparently with some hesitation) that it was during this latter period† that the lakes of the Lochaber district originated. He also, like AGASSIZ, attributes their formation mainly to two great glaciers, but differently disposed. One issuing from Glen Arkaig, and crossing the Great Glen,—at that time probably filled with ice from its summit level at Loch Oich to Fort William,—closed Glen Gluoy, and then flowed with the main stream over the shoulder of Strone-y-Vaa to near Tiendrish. Whence he concluded (p. 246), "that the Glen Arkaig glacier not only blocked up Glen Gluoy, but also largely contributed to close the mouth of Glen Spean"—aided on the opposite side by a glacier from Coire 'n Eoin.

The other glacier issuing from Glen Treig, "and protruding across Glen Spean until it rested on the hills upon the north side of that valley," blocked up the pass of Glen Glaster, while one main stream, turning westward, extended to the entrance of Glen Roy, where it served to dam the Glen Roy lake during its two higher levels, and another passed up the Spean Valley and through the pass of Makoul into the basin of the Spey. "This," he observes, "would cut off all outlet to the eastward, both by Glen Glaster and Makoul, and, so long as the icy barriers maintained a sufficient

* "On the Parallel Roads of Glen Roy, and their Place in the History of the Glacial Period," Quart. Journ. Geol. Soc., vol. xix., p. 235, 1863. See also Mr. JAMIESON'S "Ice-worn Rocks of Scotland," Ibid., vol. xviii., p. 164, 1862; "History of the last Geological Changes in Scotland," Ibid., vol. xxi., p. 161, 1865; and "Last Stage of the Glacial Period in Great Britain," Ibid., vol. xxx., p. 328, 1874.

† Sir CHARLES LYELL, who adopted the hypothesis of Mr. JAMIESON, was of opinion not only that the lakes were formed in times long subsequent to the principal glaciation of Scotland, but also that they might have been as late, especially the lowest one, as that portion of the Pleistoçene period in which Man coexisted with the Mammoth.—'Antiquity of Man,' 4th edit., p. 312.

height, the water filling Glen Roy would have to escape by the col at the top of that glen into the head of Strath Spey. This col, therefore, would determine the level of the lake, and keep it at the upper line as long as this state of things lasted.

"Now let the Glen Treig glacier shrink a little. This would open the Glen Glaster col, and let out all the water above its level. That watershed would now determine the height of the lake, and therefore keep its surface at the middle line so long as this second state of matters lasted.

"Then let the Glen Treig glacier shrink again, until it withdrew out of Glen Spean. That valley being now clear, the water would escape by the outlet at Makoul, which would then determine the level of the lake, and keep it at the lowest line so long as the ice-stream across the mouth of Glen Spean maintained itself of sufficient height. When this latter finally gave way, Glen Roy would at length be emptied.

"Grant, then, these two ice-streams, one in the Great Caledonian Valley and the other at Glen Treig, and the problem of the parallel roads can be solved, provided we allow that glaciers have the power to dam such deep bodies of water as must have occupied Glen Gluoy and Glen Roy."

In support of this view, Mr. JAMIESON shows that Glen Arkaig is glaciated to the height of 700 feet and more, and that at the entrance to Glen Treig the glacial striæ reach a height of 1,800 feet above the level of the sea. He also found ice-striæ at the entrance of Glen Gluoy at a height of 800 to 900 feet, which he takes to indicate a movement of the ice from Glen Arkaig across Loch Lochy, in the same way that the striæ on the north side of the Spean Valley indicate the protrusion of the Treig glacier across that valley (see p. 684).

§ 3. *Objections to this Exposition*—1, *the Barriers*; 2, *the Cols.*

The Barriers.—Loch Arkaig is only 140 feet above the level of the sea, and, although the glen is 18 miles long, the cols at its head are of no great elevation—one by Glen Dessarry being under 800 feet, and another by Glen Pean under 500 feet high. The mountains at that end of Glen Arkaig attain a height of from 2,800 to 3,200 feet, whilst those nearer its entrance do not exceed 2,700 feet in height. With mountains of this height, and with these low cols forming channels of outlet to the west coast, the eastward ice-stream could hardly have attained such dimensions as to traverse Loch Lochy, here 456 feet deep, and ascend the opposite hills to a height of at least 1,200 feet: still less so if an ice-stream had existed in the Great Glen.

The Glen Treig glacier, rising in the higher mountain chain of Ben Nevis, would have had greater power, but still it seems to me incompetent to the task assigned to it. This glen, although 10 miles long, is occupied for a length of $5\frac{1}{2}$ miles by the loch, which is 784 feet above the sea. To block Glen Glaster col the glacier would have to cross Glen Spean, and then to travel 2 miles with a rise of not less than 500 feet;* and if it reached the top of the pass what was there to stay its further progress?

* The bottom of the Spean Valley is here about 600 feet above the sea level.

Not only, however, is there the difficulty of conceiving a sufficient *vis à tergo* as to force these two glaciers, after crossing their respective valleys, up the opposite heights, but considering the breadth and direction of these valleys it is almost impossible to avoid the conviction that their whole mass would have taken the lines of least resistance, and turning laterally into Glen Spean and the Great Glen, have joined the ice-streams escaping through them.* That this was the case with the Glen Treig glacier is I think, as presently explained (p. 684), shown by the direction of the ice scratches in that part of the Strath Spean immediately opposite the glen.

Mr. Jamieson does, in fact, carry a portion of each glacier for some distance down these valleys, so that one blocked up the entrance of Glen Roy, and the other the entrance of Glen Spean—but in doing so he seems to me to attach too much importance to their individual action.

The formation of the small lake of the Merjelen See, in the Swiss Alps, has been adduced in illustration of the power of glacier barriers. But this lake is under 1 mile in length, by $\frac{1}{4}$ mile wide, with a mean depth of 22 to 25 feet and of 114 feet next the ice;† and although it is supported by the Aletsch glacier, which descends 5 miles lower, and has opposing buttresses in the mountain slopes on the other side of the glacier a mile wide, nevertheless the water escapes almost every year, and the lake drains in the course of a few hours through crevasses in the great glacier. Another season, however, repairs or removes the breach, and the lake refills. But it must be borne in mind that the source of the glacier is much above the level of the lake, and that the dimensions of the lake bear no proportion to that of the glacier, so that the escape of this comparatively small volume of water would have little effect on so large a mass of ice; and that the lake is not in the path of the glacier.

These Lochaber lakes, on the contrary, were respectively 5, 10, and 22 miles long, and at least 700, 800, and 650 feet deep at their lower end. With the hydrostatic pressure due to bodies of water of these heights, no single glaciers, especially when operating at their weakened extremities, seem competent to deal.

Not only so, but even with glaciers filling the larger valleys, although small lateral lakes are often formed, as in the case of the Aletsch glacier, and as appears to be more common with some of the Himalayan glaciers, these lakes are never permanent for a length of time. It would seem that their escape is not usually effected by rupture of the glacier, for after the event the glacier remains apparently unaltered, but by the circumstance that while at one time the ice of the glacier is compact and unbroken, at other times it is fissured and broken, so that when in the progress of the glacier a continuous fissure is brought in front of the lake, its waters at once escape with greater or lesser rapidity, but never with the suddenness of the bursting of a

* [In a letter recently received, Mr. Jamieson explains his views on this point more fully. He says that he considered there had been an immense accumulation of ice in the valley of the Spean opposite the entrance to Loch Treig, and that this ice had set out from that point as from a summit level or watershed in two great streams, one of which, with the united ice drainage of the lateral glens, took an eastward route by Loch Laggan to the Spey basin, while the other flowed westward down Glen Spean.—Oct. 1879.]

† Dollfus-Ausset, 'Matériaux pour l'Étude des Glaciers,' vol. v., p. 458.

lake formed by the smaller lateral glacier crossing the main valley. With the further progress of the glacier, the fissure is carried lower down the valley and again the lake basin is fronted by a solid and compact ice, and the lake refills.

With the great length of time required by Mr. JAMIESON, and with the continued travel of the glaciers, it seems impossible but that the ice-barriers of the Lochaber lakes should have presented from time to time fissured portions by which their waters would have escaped, and the escape of such large bodies of water could hardly have been effected without producing a more damaging and permanent effect on the barriers than is caused by such small lakes as the Merjelen See, or even their total removal.

It is true, that if, as in the case of such glacier lakes, the escape were only temporary, their waters might, apart from these occasional accidents, be considered as virtually permanent, for they could continue to fill to the one level, as often as they were emptied. But besides the doubt whether a breach made by the much larger bodies forming the Lochaber lakes could be readily repaired, is the doubt whether, looking at the great size of those lakes, they would have had time to refill up to the level of the cols before the movement of the glacier brought other fissures into play. It must be remembered, also, that in the Merjelen See and other such lakes the broadside presented by the glacier is but a few hundred feet in length, whereas the Lochaber barriers were to be measured by several thousands of feet, and consequently the chances of fissures occurring would be proportionally increased. If, on the other hand, owing to the change of climate, the glaciers were no longer advancing, is it possible that ice-barriers, so durable as to have lasted during the many ages required on this theory for the formation of the "roads," could have existed for that length of time?

The Cols.—On the hypothesis that the "parallel roads" were formed by the long continued action of freshwater lakes in barred glens, it follows that rivers as large at least as the present Roy and Spean, must have flowed, during long successive periods, over the cols at the head of Glen Roy, of Glen Glaster, and of Makoul. The late Professor NICOL, in 1869, was the first to draw attention to the consequences of this assumption, and remarked* that in none of the cols "is there the slightest trace of an ancient river," such as there must have been, had "each of these passes been the exit of a river of considerable size and flowing in a narrow valley for a long period." This important objection is confirmed by facts incidentally mentioned by other observers.

At the same time, Professor NICOL sees in all the cols evidence of water action compatible with what he considers might have been incidental to a narrow sea-strait. In the Glen Gluoy Pass he found a line of stones on either side, but no indication of any stream of water having ever run along it. Over the pass from Glen Roy to Glen Spey, a considerable river, in all probability larger than the Roy at present, would have flowed and left its impress.† But no notch is cut there, or on the sloping declivity down to Loch Spey, nor has any delta been formed. On the contrary, the bottom of the

* Quart. Journ. Geol. Soc., vol. xxv., p. 284.

† Even the tiny stream from the Merjelen See has cut a channel through moraine matter (LYELL).

pass is broad and flat, but, at the same time, he notices a mark horizontally running along the side of the hill, with a distinct line of stones left by the water.

When the lake stood at the level of the second "road" in Glen Roy, Mr. MILNE HOME has shown that it must have drained over the col at the top of Glen Glaster and the river have flowed along its summit level and down the declivity to the Rough Burn. Here, again, Mr. NICOL points out that, had such been the case, the river should, with the duration ascribed to the lake on the theory of the "roads" being the result of prolonged shore-action, have cut for itself a deep and long gorge down the pass, just as the drainage of the same hydrographic basin has effected in the present river channel. But the summit level of the col is flat and unindented, and thence to the Rough Burn there is only the narrow and unimportant channel of the present small rivulet, and no trace of the existence of a large stream. Nor does he see any evidence of river action in the pass of Makoul, though he allows that a river might have flowed through that narrow ravine without leaving any very deep trace behind. The lines of shingle often occurring in these passes he considers to be old sea beaches, and he, like CHAMBERS, concluded that the passes were old straits.*

Other observers have put a different construction on these indications of water action. Of the Makoul Pass, Mr. JAMIESON says that the crags on either side have been ice-worn, but that below a certain level these "markings are effaced and the rock worn into smooth sinuous curves," forming water-worn ledges strewed with "well-rounded balls of stone as large as cocoa-nuts," while in the sheltered bends or lee-side of the crags are large heaps of pebbles, affording "good proof that a strong brawling current had long gone out here;† while Mr. MILNE HOME‡ speaks in general terms of an old river course on the Glen Gluoy Pass, remarking that it is 40 yards wide, and that the rocks are much worn. He notices similar features in the Glen Roy Pass. In the Glen Glaster Pass he found no sand or gravel, but numerous spherical boulders. His opinion is, however, that in all these passes there are appearances as of the former passage of much greater volumes of water than can be accounted for by the present streams—an opinion in which I agree.

Neither he nor Mr. JAMIESON make any mention of narrow and definite channels such as would have resulted from the long-maintained action of these rivers. Had any such existed they could hardly have escaped their notice and argument.

§ 4. *The Terraces of* MACCULLOCH ; *the Deltas of* CHAMBERS *and* JAMIESON.

In the absence of river channels, Mr. JAMIESON has relied on evidence of another class, viz. : that of the so-called deltas, in proof of the long duration of the Lochaber lakes. Amongst the most important of these mounds is the one in Glen Turret, which he ascribes to the action of the small stream of the Turret, remarking, however, that it "is more than twice as big as that of the Roy," which should have had "much the

* 'Ancient Sea Margins,' pp. 95 and 111. † Quart. Journ. Geol. Soc., vol. xix. p. 243.
‡ Trans. Roy. Soc. Edinb., vol. xxvii., p. 597.

larger delta," and is "out of all proportion to the size of the stream." He describes it as "some furlongs wide," with "a front rising at its centre 90 feet above the bottom of the valley—a striking proof how long the lake must have existed. The fan-shaped margin shows that the water it dropped into had no strong set or current."*

This mound is certainly a remarkable object, and has attracted the attention of all observers since MACCULLOCH's first description of what he considered to be alluvial lake-deltas terraced by later river action. Its surface, however, is not an inclined plane, nor is there any sorting of its materials from its head at the Turret Pass to its extremity on the Roy. On the contrary, the mass of débris is less at the foot of the Turret Pass, where there is the following section (fig. 1) on the river bank, than lower down, and its component parts are no finer at the one place than at the other.

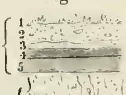
Fig. 1.†

a. Gravel horizontally stratified. 10 feet?
m. Light grey loam with angular débris and blocks in inclined rough bedding. 20 feet?

From this point the surface of the mound at first falls slightly, and then gradually rises until it attains, at the further end near the Roy, at the distance of a mile, a height of 80 to 90 feet above the river—the very reverse of the form that a delta should exhibit. Its mass, too, is out of all proportion to the size of the Turret, for it covers an area fully equal to a mile square, and averages probably a thickness of 50 feet. It consists, also, in larger proportion of an unstratified detritus, with a small capping, of very variable thickness, of stratified water-worn débris.

Fig. 2 shows the upper water-worn portion of the mound at its extreme end.

Fig. 2.



Section of top of mound facing the Roy, half a mile north of its junction with the Turret.

1.	Surface soil	6 to 8 inches.
2.	Greyish clayey sand with worn fragments and a few large angular pieces of the local rocks	6 feet.
3.	Fine angular and subangular débris of the same	$1\frac{1}{2}$ "
4.	Very finely laminated yellow clay	3 "
5.	Very finely laminated grey clay	3 " +

t. Talus from the beds above covering the unstratified detritus *m.*

The thickness of No. 5 shown here is uncertain: it appears not to exceed 4 or 5 feet.

* Quart. Journ. Geol. Soc., vol. x., p. 242.

† The sections from nature throughout the paper are on the same vertical scale of 40 feet to 1 inch unless mentioned to the contrary.

The base of the mound is better seen in sections on the banks of the Turret, which expose a mass of unstratified light grey sandy clay, from 50 to 80 feet thick, full of angular fragments, including a few large blocks, of the local rocks. Its general appearance, viewed in front and looking towards Glen Turret, at its terminal slopes facing Glen Roy, is shown in the following sketch.

Fig. 3.

View looking down Glen Roy from its junction with Glen Turret.

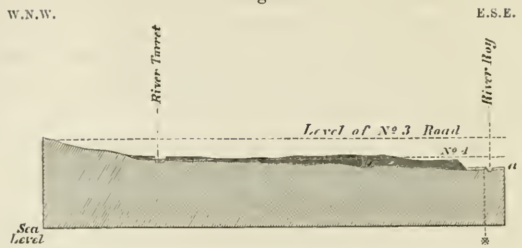
a'. Bed of river gravel. *b*. Detrital mound of the Turret valley. 2, 3. The upper two parallel roads. The lower "road" No. 4.

The want of continnity in the "mound" is due at the first break to the passage of a roadway, and at the second to the passage of the Turret.

I do not see therefore how this deposit can be due to delta formation. Not only is the accumulation of the main mass at the most remote instead of the nearest point of discharge, but there is an absence of the bedding or stratification that would belong to a deposit formed in tranquil lake waters. It appears to me to be moraine detritus, brought down from Glen Turret and its tributary glens descending from Ben Erin and the other hills at the head of the glen, subsequently worn and remodelled on the surface by water action (post, p. 688). Its present terminal slopes are clearly due, as pointed out by MACCULLOCH, to the River Roy, which has undermined and removed that portion of it, and of the other such mounds, which projected into the Roy Valley, while the loose débris at top has fallen down and formed slopes, the angle of which is almost invariably one of 40°.

The following is a diagram section, from the foot of the Turret Pass at fig. 1, to the Roy at fig. 3.

Fig. 4.



Section of Glen Turret detrital terrace mound from the Turret at the foot of the pass into Glen Gluoy to the River Roy, a distance of 1 mile.

a'. River gravel. *b*. Detrital mound. * Ice-worn surface of rock.

It is true that the top of this terrace corresponds approximately with the level of No. 4 "road," but the several other similar smaller mounds lower down Glen Roy bear no relation to that level. They follow the fall of the valley, and gradually increase their depth beneath the road with their distance from the head of the glen.

The great mound at the west end of Loch Laggan is in the same way considered to have been made by the discharge of the Gulban river into the lake which filled Glen Spean to the height of the "parallel road" No. 4. I had not the opportunity of closely inspecting this mound, but from what little I saw of it, I should refer it to the same origin as the one in Glen Turret. Mr. JAMIESON says that the front of it is about 20 feet above the level of the loch, and that it rises 50 feet. Now as the level of the lake is 819 feet, this would make the height of the front of the so-called delta say 840 feet, the level of the pass of Makoul being 848 feet; so that, although the delta at its lower end would have been about 10 feet below the surface of the lake, its upper portion would have been 40 feet, if not more, above the level of the lake waters. Mr. JAMIESON states also that the delta "at the mouth of the Rough Burn is at a level corresponding with the lowest of the parallel roads;" but that "the top of the delta rises considerably above this line." It is, therefore, not easy to see how these mounds or terraces could be deltas formed in the old lake, the level of which was that of the pass of Makoul. There are also similar terraces, often much below the old lake level, where there are no tributary rivers, as in the case of the one on which the village of Inverroy stands, that above Inch, and others in the Spean Valley (see fig. 23, p. 716). The fine examples off the entrance to Glen Treig are well known; sketches of them by Captain WHITE are given in Sir HENRY JAMES's 'Notes.'

§ 5. *The Level of the Snow-line.*

Lastly, there is another, and as it seems to me a fatal, objection to Mr. JAMIESON's hypothesis, in the excessive inequality in the level of the snow-line in closely adjacent districts which it would necessitate.

It would, as he observes, "require us to suppose that the ice was much more developed in Ben Nevis and the region to the west of the Caledonian Canal than in the hilly district around the sources of the Spey.* . . . . Otherwise they (the glaciers), would have occupied the watersheds or cols at the time the terraces show they were clear of ice."

The reason he suggests for conditions so anomalous, is a difference in the precipitation of snow such as now exists in the rainfall of the same districts. He refers to the mean annual fall at Fort William of 86 inches, and at Loch Nevis of 82 inches,† whereas at Laggan it is only 46 inches. But Laggan is as far from the hills in question as is Fort William, and more recent observations given by Mr. SYMONDS ('British Rainfall,' 1876–7) show that the rainfall at the Bridge of Roy is in fact 62 inches annually, and that that place comes within the line of above 50 and under 75 inches fall.

Mr. JAMIESON'S view is, however, supported by the authority of Professor TYNDALL,‡ who considers that the position and greater height of the mountains south of Glen Spean caused them to intercept the moisture carried by the Atlantic winds which would therefore have reached the hills north of that glen in a state of greater dryness and warmth.

But the difference alone between the height of the hills from the west coast at Mull to Ben Nevis and of the hills eastward of Ben Nevis, is, on the whole, with the single exception of this and one adjacent mountain, so small, that the effect of greater condensation could have been only of a very limited local character, apart from the general decrease which everywhere obtains in proceeding from the west to the east coast.§ That this general condition contributed however to a much larger development of the ice-sheet on the west coast than on the east is tolerably certain. Its dimensions in Skye and on the north-west coast seem to have much exceeded anything in the more eastern counties. It is also probable that the formidable block of ice on the west coast was the cause of the eastward movement of a large portion of the ice-sheet and afterwards, for a time, of the surface waters. But this is part of a general phenomenon to which the Ben Nevis range is subordinate, and could hardly have been productive of any extreme differences in such closely similar and conterminous districts.

It must further be borne in mind that the land probably stood higher, and that the coast line was considerably farther distant from Ben Nevis at the period referred to than at present (see § 11). Still the relative height of the hills would have been much the same then as now, when with the exception of Ben Nevis which is 4,406 feet, and

* Quart. Journ. Geol. Soc., vol. xxx., p. 335, 1874.

† Glen Qnoich, where the fall is 102 inches, is also mentioned, but this lies in another direction 20 miles N.W. from Glen Spean.

‡ "On the Parallel Roads of Glen Roy," Proc. Roy. Inst. of Gt. Britain for June, 1876, p. 11.

§ Glen Roy lies N.N.E. of the Ben Nevis range, so that westerly and W.S.W. winds would reach it without passing over those mountains.

of Cronach Beag 4,060 feet high, there is no very material difference in the altitude of the hills north and south of Glen Spean. The other mountains of the Ben Nevis range on the *south* side of the Spean Valley are respectively 3547, 3217, 3658, 3433, 3569, and 3443 feet in height; while the range on the opposite *north* side of the Spean Valley, including the Glen Roy area, measure 2736, 3422, 3700, 3441, and 3298 feet. Those again which encircle Loch Arkaig are on the north side 2398, 2636, 1802, and 2680 feet; and on the south side 2613, 2373, 3224, and 3164 feet in height, or of less elevation than those between Glen Roy and Loch Laggan.*

Surely under such nearly similar conditions, "is it," as Mr. MILNE HOME observes, "likely that in this Lochaber district some glens should have been filled with solid ice and others with water?" Why should the Arkaig hills have their huge glacier, and the neighbouring range north of the Spean, at the same time, none?

For the reasons assigned to have any force, it should be shown that in the district still further east, where the rainfall is under 50 or even under 40 inches, and there are mountains of the equal height, there was, at the same period, a similar absence of glaciers; but the observations of Mr. JAMIESON himself in Aberdeenshire, as well as those elsewhere of other Scotch geologists, show that during the second glacial period there were local glaciers amongst hills of the same height as those of Glen Roy, and where the rainfall is no greater, but even less than in that district. CHAMBERS, speaking of the local systems of the later or second period of glaciation, remarks that, "wherever there are mountains in Scotland approaching or exceeding 3,000 feet in height, there have glaciers existed," and mentions many in the valley of the Dee,† where according to SYMONDS's hyetographical map the annual rainfall is only between 30 and 40 inches.‡

Although the presence of the Merjelen See, at a height of 7,700 feet, shows how an open lake may co-exist by the side of a large glacier, the conditions are entirely different to those which obtained in Lochaber. This small lake is some 1,200 to 1,500 feet below the snow-line, but the Aletsch glacier, by which it is dammed up, has its origin in mountains from 12,000 to 14,000 feet high, and both lake and glacier belong to the same mountain range. The lakes of similar character in the Himalayas are also considerably below the level of the snow-line, and are fed by small tributaries, whereas most of the feeders of the Lochaber lakes, being in main valleys, have their rise among the higher summits at heights which must have been above the snow-line, and should have furnished glaciers rather than streams of water. Either the snow-line, if higher,

* An ordnance map of Mr. J. F. CAMPBELL's, in which he has coloured the surfaces above the 3,000 feet contour line, shows that the area above that level on the north of the Spean valley is very little less than that on the south.

† Edin. New Phil. Journ., vol. liv., p. 254, 1853.

‡ The great ice-sheet of Greenland seems to be maintained without any heavy rainfall. Dr. RINK ('Danish Greenland,' 1877, p. 377) found the annual fall of snow and rain at Julianehaab, in South Greenland, during his few years' residence, to average 37 inches, and says that the fall of snow in North is less than in South Greenland; but the gauges yet are few, and nothing is known of the fall on the east coast.

say, than 3,000 feet, would not have allowed of the maintenance of the large blockading glaciers, or else, if even not lower than 1,500 to 2,000 feet, would not have allowed of the existence of such large bodies of open water.

The snow-fields supplying the Alpine glaciers extend over a zone 4,000 to 5,000 feet in height. In Norway, this zone is not more than 2,000 to 3,000 feet, but compensation is found in the great superficial extent of the fields. Notwithstanding this, the glaciers in both countries are of much smaller size than those attributed to Glen Treig and Glen Arkaig. To furnish such glaciers it is scarcely possible to suppose that the difference between the mountain summits and the level of the snow-line could have been less than in the countries referred to, and if not less, instead of open lakes, glaciers must have filled all these glens of the mountains alike to the north and the south of Strath Spean.

If on the contrary the lakes were formed during the retreat of the glaciers (as would be implied by the retreat of the Glen Treig glacier from Glen Glaster col), then it is not possible to suppose that the main ice-barriers, no longer fed by fresh supplies, could have existed during the great length of time required on this hypothesis for the formation of the roads by erosion and of the mounds by delta deposition.

Views of the Author.

Although I consider there are the foregoing objections to the exposition of the glacial theory so ably propounded by Mr. Jamieson, I believe with him and with Agassiz that this theory affords the most satisfactory solution of the problem, but I would suggest a somewhat different interpretation in explanation of the build of the barriers and the formation of the "roads."

I have before mentioned that Agassiz, after showing the great extent of ice-action in Scotland, sought to explain the origin of the lakes of Macculloch and Dick-Lauder by a system of glaciers issuing from Glen Arkaig, Glen Treig, and from the side of Ben Nevis, and that later observations had led Scotch geologists not only to verify the intensity of the first great glaciation of the country, but also to conclude that it was succeeded by a milder period, when a great submergence of the land took place, and then again by a second cold period during which the chief mountain ranges formed centres of local radiating glaciers of limited extent.

Dismissing, for the reasons before assigned, the hypothesis of local glaciers, I fall back upon the original theory with the development given to it by more recent research. I would attribute the origin of the Lochaber lakes—not to the incoming of a second cold period and to special glaciers damming back the streams, and so giving rise to lakes of which the "roads" are the old shores formed by the long-continued action of the lake waters,—but to causes of a more transient character connected with a phase of the early or first glacial period.* I feel that this view is not

* If it should be proved that the second glaciation was of extent equal or nearly equal to that first

without its difficulties but that they are fewer than those presented by the other hypotheses, while it will, I think, be found to meet some of the many of the objections which have been raised to both the lake theories. I regret that the time at my disposal did not allow me to see all the points I could have wished, but the various and accurate researches of previous observers have sufficiently supplemented the data required for my object.

§ 6. *Depth of the Ice-sheet in Lochaber: Extent of the Glaciation.*

It is not necessary to discuss the general glaciation of Scotland and the extent of its great ice-sheet. For our purpose it is merely needed to determine its dimensions in this and adjacent district. The observations relating to this subject are not so numerous—especially at heights—as could be desired, still they are enough to prove the vast thickness of the ice at the period of the great first glaciation.

Mr. MACLAREN, in his paper "On Ground and Striated Rocks in the Middle Region of Scotland,"* mentions generally that the effects of ice abrasion in the range of mountains south of the Spean Valley can be traced to a height of more than 2,000 feet.

Mr. MILNE HOME states† that smooth rock-faces at the entrance to Loch Treig extend to the height of 1,680 feet; again, that there are ice-worn surfaces on the west and south sides of Craig Dhu at a height of 1,800 feet, and on the west side of hill N.E. of Rough Burn at 1,600 feet above the sea. He mentions also that he found at the head of Glen Roy rocks with their smoothed surfaces facing west, and lower down on the south side of Glen Roy, nearly opposite the Gap, other smooth surfaces at a height of 1,238 feet; on the west side of Glen Gluoy above Alterahary Farm at 1,300 feet; on the hill between the latter and Glen Fintaig at 1,700 feet; in Glen Glaster pass facing west, and on the west side of the hill one mile east of Loch Treig, at 1,600 feet.‡ In a later paper,§ quoting from a MS. of Mr. JOLLY, he instances glaciated rocks on Ben Chlinaig facing Glen Spean at a height of 1,750 feet, and in the Laire Valley at 1,600 feet.

Dr. R. CHAMBERS‖ noted an ice-abraded rock at the top of Glen Glaster with the smoothed side to the N.W. He refers also to many glaciated surfaces at from 1,700 to 2,000 feet, but not at greater heights.

Mr. JAMIESON examined in particular Glen Treig and Glen Arkaig for evidence of glacial action at heights. At the entrance of the former he found ice-striæ as high as 1,280 feet above the level of the loch, or more than 2,000 feet above the sea, but is of opinion that ice action extended even higher. In Glen Spean he "was struck with

glaciation, then there would be no objection to place the "roads" at the end of the second period. In fact, it would be necessary, as the second glaciation must then have obliterated any "roads" of the first.

* Edinb. New Phil. Journ., vol. xlvii., p. 161, 1849.

† Trans. Roy. Soc. Edinb., vol. xvi., p. 412.

‡ Ibid., vol. xxvii., pp. 634–638.

§ Trans. Roy. Soc. Edinb., vol. xxviii., p. 98.

‖ Edinb. New Phil. Journ., vol. liv., p. 254, 1853.

the greater wear and smoothness of the hill slopes flanking the valley below a level of about 2,000 feet or so."* In Glen Arkaig he traced glacial striæ up to 700 feet above the loch,† and believes them to extend higher. On the north side of Glen Gluoy, at the angle of the ridge between it and Loch Lochy, Mr. JAMIESON found, at about 260 feet above the bridge, glacial striæ pointing W. 25° N.; again, on the shoulder of the hill between Glen Gluoy and Glen Spean at an elevation of probably 800 to 900 feet, striæ pointing W. 5° N., and a little lower others directed W. 20° N. "running, not horizontally, but up and down the slope;" while nearer Glen Spean and at a lower level were striæ pointing W. 15° N., W. 45° N., and W. 12° N., or as though directed from Glen Arkaig, with most rock wear on the western side. At Blackletter he found the striæ point W. a little N. In Coire 'n Eoin they were northward down the glen.‡ In a later paper Mr. JAMIESON speaks of hills of 2,000 feet, the summits of which exhibit ice-worn surfaces, but does not give the particular localities.§

Professor TYNDALL says that at the head of Glen Glaster all the dominant hills are intensely glaciated.||

In adjacent districts Professor A. GEIKIE records some instances of glaciated surfaces at heights of from 1,500 to 2,000 feet, but notices very few exceeding those heights:¶ while Dr. J. GEIKIE states generally that in the Western Highlands ice-scratches may be traced from the islands and the coast line up to an elevation of at least 3,500 feet, and "that the ice could not have been less and was probably more than 3,000 feet in its deeper parts."**

In the second Report of the Committee on Boulders, it is recorded that traces of ice-wear exist on the north and west sides of Ben Trishlih, on the north side of Loch Linnhe, at a height of 1,566 feet.††

My own observations were confined chiefly to the glaciation at lower levels, which is so general, and has been so often noticed, as to require no special description. Wherever in the valley of the Spean the bare rocks are exposed, they are almost everywhere rounded and *moutonnées,* but are generally too much weathered to show the direction of the striæ. Such glaciated surfaces are especially frequent between Roy Bridge and Loch Laggan, and on higher ground they are conspicuous on the south-west flank of Craig Dhu, below and above No. 4 road; on the south flank of Tombrahn, at the head of Glen Roy, under and above "roads" Nos. 2 and 3; and at the entrance to Larig Leacan, at a height of from 1,000 to 1,200 feet. The Leacan there flows through a narrow pass, the rocks on both sides of which are strongly glaciated and

* Quart. Journ. Geol. Soc., vol. xviii., p. 172.

† Or 840 feet above the sea.

‡ Quart. Journ. Geol. Soc., vol. xix., 245–246.

§ Ibid., vol. xxx., p. 328.

|| Proc. Roy. Inst. Gt. Britain for June, 1876, p. 10.

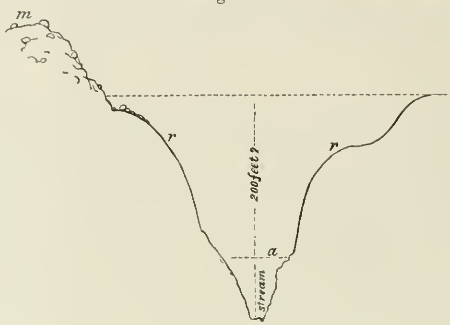
¶ 'The Glacial Drift of Scotland,' pp. 16–34, 1863.

** 'The Great Ice Age,' 2nd edit., p. 65, 1877.

†† Proc. Roy. Soc. Edinb., vol. vii., p. 161, 1875.

rounded, while above, at *m*, are heaps of coarse moraine detritus. Fig. 5 is an outline section : the rounded rock surfaces *r* extend apparently to about the level *a*.

Fig. 5. W.



Outline section of the ravine at entrance of Glen Larig Leacan.

The "erratic blocks" so abundant over this district furnish additional evidence of the height and direction of the ice-sheet, though as yet only a limited number have had their exact position and origin determined.*

Mr. DARWIN found granite boulders on the hills between Glen Roy and Glen Gluoy, at heights of 1,600 to 1,700 and 2,200 feet; on Meal-Dubh above 972 feet; in the Gap of Collarig on and about the upper terraces ("roads"); in the valley of Glen Roy; and on the side of Tombrahn.† He considered that they may have been derived from the granite hills near the source of the Roy.

Mr. MILNE HOME‡ found transported boulders on Bohuntine Hill at 800 to 1,100 feet; at the head of Glen Glaster at 1,000 to 1,200 feet; and at the head of Glen Roy at 1,320 feet. He also states that thick beds of sand and gravel occur on the hills around Glen Gluoy at heights of from 1,700 to 1,800 feet; on Ben Chlinaig at 1,700 feet; and on the hill N.E. of Rough Burn at 1,700 feet. Mr. MILNE HOME, however, attributes these and other blocks and drift beds to floating ice, carried from the W. and W.N.W., and to marine action.

Mr. JAMIESON found near the summit of Craig Dhu (2,161 feet), and on the top of Bohuntine Hill (1,750 feet),§ transported boulders of a "syenitic granite," which he traces to rocks of this character in the valley of the Spean opposite Glen Treig. He traced other boulders of the same rock up the valley as far as Makoul.

* The Boulder Committee of the Royal Society of Edinburgh is collecting valuable data relating to this subject—data essential to settle definitely the question of transport of these blocks by land or sea ice.

† Mr. DARWIN takes the heights of the "roads" given by MACCULLOCH, which, as he suspected, have been found to be about 100 feet too high, so a correction to this extent has to be applied to these and some other heights given in his paper.—*Op. cit.*, p. 68.

‡ Trans. Roy. Soc. Edinb., vol. xxviii., p. 640.

§ Quart. Journ. Geol. Soc., vol. xviii., pp. 174–176.

Although the data thus furnished by the position of the glaciated surfaces and erratic blocks are not numerous, still they are sufficient to lead to the conclusion that, on the Ben Nevis range the ice-sheet may have extended to a height of from 3,000 to 3,500 feet; and on the hills to the north of the Spean to a height of not less, and possibly more, than 2,000 to 2,500 feet. The facts may seem somewhat conflicting, but considering the complicated movements that must have attended the growth of the ice-sheet, they can hardly be otherwise until we have more precise data respecting the direction of the striæ and the origin of the boulders (see Map, Plate 46).

For this great mantle of ice necessarily commenced with local glaciers descending from every mountain range, and, as those of one group became confluent in the glens of that group, they flowed into the wider intervening valleys, where they met with the glaciers of other ranges. Here they would consequently become subject to much mutual interference, causing deviation and deflections from their normal course into lines altogether aberrant and dependant upon the relative mass and force of the contributory glaciers. In the Alps at the present day the glaciers do not go beyond the first local stage, being confined to the separate slopes of each mountain group, and ending on reaching the intervening valleys, so that in no case do the glaciers of one mountain group come into collision with those of another range. But amongst the mountains of Scotland, where the number of local centres was great, the gradients variable, and the interferences frequent, the results produced have nothing analogous in the existing glaciers of Europe. Geologists have sought for such conditions in the ice-sheet of Greenland, and of this we know little except at its borders.

Owing to the conflicting forces thus brought into play, the old ice-sheet, as is well known, did not always follow the natural channels of drainage, but was constantly forced, not only up valleys, but over intervening ranges of hills. At the points of junction of opposing glaciers, blockages must also have often ensued that tended to heap up and accumulate, not only large bodies of ice, but likewise large quantities of moraine detritus. With a general movement of the whole mass seaward, it was subject to innumerable deflections at the confluence of contributing glacier-systems of variable force, and to formidable checks and stoppages at those points where the ice-masses were in more direct antagonism in valleys open to many tributaries, or where the main valley was blocked previous to the descent of the glaciers from the tributaries. The ice would then necessarily take the lines of least resistance, and no longer be guided by the lines of natural drainage.

At the present day, the effects of conflicting ice-masses are confined to the compression by confluent glaciers in the narrow glens or in higher and more open mountain basins. Under certain circumstances this may give rise to the horseback ridges of some glaciers,* and to the convexity noticed in some great central ice-areas. Sir

* I cannot conceive that the medial ridges of some of the Alpine glaciers, for example, can be entirely due to the more rapid melting of the ice on the sides of the glacier. Observations on this point are however wanting.

JOSEPH HOOKER* remarks on the low dome-shaped form of the ice in a basin several miles long and wide, high up in the Himalayas, which he refers to the meeting of tributary glaciers; and Colonel GODWIN-AUSTEN describes a great glacier 2 miles wide, that receives a great number of tributaries, and along the centre of which stood a continuous line of huge masses of ice, which gives the idea they may have been squeezed up.† In the same way the old glaciers, meeting and clashing with a degree of antagonism unknown amongst modern glaciers, must often have expanded vertically or have been raised and piled up, in places, much beyond their normal height.‡

That such was the case in the Lochaber district there can be little doubt. We shall, in the next chapters, have to consider what may have been the effect of these obstructions to the normal flow of the ice-currents, not only in directing and massing the ice, but likewise in the distribution of the drift, including under that term the moraine deposits and the various beds of sand and gravel so widely spread over this district.

§ 7. *Exceptional Condition of the Ice-sheet in Lochaber.*

Bearing in mind the foregoing remarks, we will now show that, owing to peculiarities in the physiography of the Lochaber district, the condition of the great ice-sheet which there obtained must have been special and exceptional. Firstly, the Ben Nevis group being higher than any of the surrounding mountains, it would, *cæteris paribus*, give rise to glaciers larger and more powerful than those of the surrounding ranges. Secondly, the surface drainage from this group, instead of following the ordinary course from the centre to the sides, is directed to the northern side alone, so that there the valleys of the Spean and the Lochy received at the glacial period an excess of ice, as they now do of surface waters. For it will be observed that all the waters which run off the south side of the Nevis group flow into the two streams of the Nevis and of the Reidh, which streams besides receive the drainage of the northern half of the parallel range of the Kilmallie mountains. The Nevis stream, which follows the course of Glen Nevis, after running several miles due west, turns suddenly northward, and debouches into the Great Caledonian Valley near where the Lochy joins Loch Linnhe. The Reidh, also, on the same south side of this range, first runs some miles due east, and then joins at right angles Loch Treig, the course of which is north, and discharges into the Spean Valley. Lastly, owing to the position of the Ben Nevis group at the junction of the Spean and Lochy Valleys, its centralised ice-drainage was thrown on the lower reaches of these valleys, causing thereby an abnormal obstruction and accumulation of the ice at the entrance of Strath Spean and the Great Glen.

* 'Himalayan Journals,' vol. ii., p. 137.

† "On the Glaciers of Mustakh Range," Journ. Roy. Geogr. Soc., vol. xxxiv., p. 40. Colonel GODWIN-AUSTEN informs me, however, that in his opinion the ice is forced up by underlying bosses of rock.

‡ In the Arctic Seas, ice floes, when squeezed together or driven ashore by strong winds or currents, pile up to great heights.

On the north of these mountains, the glaciation of Larig Leacan and of Coire 'n Eoin shows the descent of glaciers down those glens, and others no doubt descended Glens Diombadh and Mhuilinn, and the other smaller glens on the flanks of this range from Ben Nevis to Loch Treig. It will be observed that all these glens rise amongst the higher summits of the district, that their gradients are steep, and that glaciers projecting from them would, after crossing the Spean Valley, tend to mass (or force the Spean stream to mass) against the opposite range of hills between Glen Roy and Loch Lochy, and on the hills at the entrance of the Great Glen.

Besides these, the great glaciers coming down Glen Treig and Glen Nevis threw into the valley of the Spean and of the Lochy large masses of ice flanking the foregoing central glaciers of the group, so that a barrier was thus raised to the descent of the ice-stream from the upper part of the Spean Valley above Glen Treig, while the great glaciers debouching from Glen Eil and other lateral valleys into Loch Linnhe blocked up the western outlet of the Spean and Lochy ice. This mass of ice seems therefore to have been diverted northward and eastward, where the resistance was less, one portion taking a direction along the Great Glen, and another passing over the watershed of the Spean and down the valley of the Spey. The obstacles to this course are not so formidable as might at first sight appear, for the bed of the Spean Valley, to where it is joined by Glen Treig, only falls about 200 feet below the level of the pass of Makoul, over which the ice-stream of the upper tributaries passed, while the watershed of the Caledonian valley rises only to the height of 94 feet. It is a question, also, which we shall afterwards consider, whether the Ben Nevis range did not stand relatively higher then than now to the east coast, so that the eastward gradients were greater, or possibly in the Caledonian Glen were even continuous throughout.

The western portion of the great body of ice in the Spean and Lochy Valleys, diverted therefore in a direction north-east along the Caledonian Valley by the block before alluded to, met the glaciers issuing at right angles from Glen Loy, Glen Arkaig, and others on the north side of the river Lochy and of the loch of that name, and was thus driven to hug the hills on the opposite side of the Great Glen—*i.e.*, those at the entrance to Glen Spean and Glen Gluoy, massing in their front and moving up the tributary valleys where there was no counterbalancing resistance, or until checked by the local ice already in occupation of those valleys.

It appears certain that in consequence of the physical conditions just named, the accumulation of ice caused by the conflicting and opposing currents, and by the block which ensued, must have attained exceptional proportions at the entrance of the Lochy, Spean, Roy, and Gluoy Valleys, and thus formed barriers to these valleys of great height and dimensions.

The direction of the striæ noted by Mr. Jamieson near Strone-y-Vaa and at Blackletter I take to be due, not to an incurrent ice-stream from Glen Arkaig, but to an excurrent stream passing out from the lower part of the Spean Valley into the Great Glen; and, in the same way, the striæ at the entrance of and in Glen Gluoy are due to the joint action of this stream and of the great stream coming from Ben Nevis and the Lochy.* This direction of the ice-flow is confirmed by an observation of Mr. CAMPBELL, who found, at a point 1 mile N.W. of Spean Bridge, ice-striæ pointing W.N.W., indicating that the westernly ice-stream of the Spean Valley was there deflected northward towards the Great Glen. The local variations in this area may be due to variations in the flow of the ice at different periods of the growth of the ice-sheet.

With respect to the ice-flow higher up Strath Spean, I do not see how it was possible for the Treig glacier, after pushing across that valley, to have sent off two lateral branches, one up and the other down the valley, while the central portion continued to advance up the hill to the pass of Glen Glaster. Although the ice-striæ opposite Glen Treig are transverse to the valley they are not directed towards Glen Glaster, but point more westward, while lower down (the valley here runs east and west) the influence of the mass of the Ben Nevis range of glaciers shows a deflection of the ice-stream over Craig Dhu, in the direction of Glen Roy. Higher up the valley, the striæ near the Rough Burn point, not up and down the main valley, but in the direction of the hills north of Strath Spean (which rise to the height of 3,000 to 3,400 feet), as though a glacier had descended from them along Glens Feitheil and Chaoruinn into the valley of the Spean; while nearer Moy, where the valley turns a few degrees more northward, the striæ again conform nearly to the direction of the main valley. The following are the corrected bearings I took of these striæ :—

1. A little east of Tulloch	E.S.E. and W.N.W.
2. Nearly opposite Inverlaire . .	E. and W.
3. Nearly opposite Glen Treig . .	S. 22° E. and N. 22° W.
4. Near the Rough Burn	N. 7° W. and S. 7° E.
5. About $1\frac{1}{2}$ mile west of Moy . .	W. 32° S. and E. 32° N.

While therefore I agree in considering that the striæ Nos. 1, 2, and 3 are due to the Treig glacier, I think that its whole mass turned and flowed westward down the Spean Valley, and that the striæ Nos. 4 and 5 are due to other glaciers descending southward from the opposite hills into the Rough Burn and Strath Spean, where they met and were stopped by the Treig glacier, when, driven to take an easterly course up Strath Spean, they travelled in confluence with the glaciers of Glen Gulban, or Ghuilbinn, and of other tributary glens, over the pass of Makoul into Strath Spey.

Whether or not another portion of the Spean Valley ice passed up the valley of Glen Roy and over its col into Glen Spey, I think far from decided. The glaciers from the Ben Nevis range may have so dammed up the entrance to Glen Roy that no glacier belonging to that valley could pass out into Glen Spean. Nevertheless, during the first extension of the ice-sheet, the glaciers from the mountains at the head

* I am unable, however, to account for the rocks at the first of these places being most bared on their west side, unless it be due to the pressure of the great Lochy and Nevis ice-stream.

of Glen Roy must have descended along that valley, receiving tributary ice-streams from Glen Turret and Glen Glaster. Traces of the presence of this glacier are to be met with only in a few places, as the bed of the valley of Glen Roy is so filled with detrital matter that the bare rock is rarely seen. I found, however, a well-marked *roche moutonnée* close under the bridge crossing the Turret above Dalriach, and another a short distance lower down the Roy, while on the slopes of Tombrahn the rocks are glaciated both below and above the two higher "roads." I also look upon the traces of moraine detritus on the slope of the hills above Achavady (see figs. 15 and 19), and the large bed of it between Achavady and Bohuntine, as equally due to the action of this glacier.

This Roy glacier moved down Glen Roy until it met the ice from the Ben Nevis range and the Spean Valley, when a block ensued. Whether or not its course would then be reversed by the larger and stronger mass, or whether it would only be rendered stationary, while the upper part of the great opposing united ice-streams passed on and over-rode the smaller glacier, is a question for future investigation. I should presume that the latter would be the more probable case. This would be in accordance with the opinion of Mr. JAMIESON's, that an ice-current flowed outward over the col from Glen Roy; at the same time, I would suggest that the glaciation at that spot, which I had not the opportunity of visiting, if not due to the Roy Glacier may be due to a glacier issuing from Glen Agie and the other adjacent glens, and diverted eastward by the block in Glen Roy. A reversal of the entire current seems to me to be a physical impossibility, owing to the enormous inertia of the mass of ice, and the vast friction to be overcome.* At the same time, I can conceive the possibility of the Ben Nevis ice, from its much greater height and mass, over-riding the Glen Roy glacier.

§ 8. *Distribution of the Moraine Detritus.*

The many checks and blocks that must have occurred during the formation and growth of the great ice-sheet, may serve to explain much that is peculiar in the distribution of the moraine detritus, not only in Lochaber, but in other parts of the country.

In the glaciers of the Alps, where the ice-flow is uninterrupted and the gradients are considerable, the glacier detritus is carried down and deposited in front of each glacier as a terminal moraine—the materials being derived chiefly from the lateral and medial moraines, while the subglacial detritus or *moraine profonde* usually contributes but little; for so long as the glaciers remain confined within the walls of narrow and steep ravines, so long do they press forward on their beds with such force as either to leave the rock bare, or else to reduce the quantity of silt and stones

* Unless, possibly, the work were very gradual and prolonged, the upper layer of the underlying glacier being first moved back by the advancing Ben Nevis ice, and so on successively as layer after layer came under its action.

intervening between the rock and the glacier to the smallest possible amount. It is only when the glacier issues from these contracted ravines into valleys where the ground is comparatively flat, and where the ice is free to spread out laterally, that it loses its extreme power of abrasion, and may pass over detrital matter without causing disturbance, except by the direct action of pressure. CHARPENTIER* mentions that on one occasion the Glacier du Tour, in the valley of Chamouni, descended into that valley, and advanced a distance of 80 feet over a bed of gravel. When at the end of five years the glacier retreated, the gravel was found to be undisturbed, and even the tufts of Alpine plants on its surface were found in their place.†

Mr. DOUGHTY‡ notices a similar state of things in some of the Norwegian glaciers. Alluding to the *ploughing-out* power of glaciers over loose materials, he says: "From what I saw in the Norwegian glaciers, I should believe this action has been rather exaggerated: the snout of the glacier ploughs out a little, and *rises over the rest.*"§ From the plate accompanying his paper I imagine that this happened where glaciers debouched into a transverse valley with small gradients.

Colonel GODWIN-AUSTEN,‖ although he describes the disturbing power of glaciers in ploughing up the soil and turf, also speaks of some of the glacier moraines of the Himalayas overlying loose sand in the bed of valleys.

So when the glaciers of the Lochaber and other mountain ranges emerged from the contracted glens down which they first descended, into the broader and more open river valleys, they probably spread out and over some portion of the moraine débris, previously swept down in their front, before they coalesced and formed another stream. It is to be presumed, also, that in the case of glaciers meeting in opposition, their driving force would be more or less neutralised or stayed, according to the angle at which they met. In the Alps, where each glacier system is limited to its own centre, and there is no clashing of opposing glaciers in intervening valleys, we have no means of judging what would be the results of such conditions, but in Scotland, during the growth of the great ice-sheet, such clashing was inevitable It is not as where glaciers meet at a small angle, and, becoming confluent, continue uninterruptedly a downward course; but where, issuing from glens belonging to different mountain chains into intervening valleys, they not only meet with altered gradients, but come also into direct collision with the glaciers of other systems. In these cases

* 'Essai sur les Glaciers,' pp. 42, 97, 1841.

† DOLFUSS-AUSSET mentions that the lower glacier of the Aar, where the gradient is small, passes over and buries the materials composing the terminal moraine; and he instances a large block which was 10 metres in front of the glacier in 1848, 2 metres in 1849 when it was nearly hidden by other débris, and in 1850 was covered by the ice, and has not since (1864) been seen.—*Op. cit.*, vol. v., p. 415.

‡ 'On the Töstedal-bræ Glaciers,' London, 1866.

§ The italics are mine.—J. P.

‖ *Op. cit.*, pp. 24, 47. The author informs me that sand and gravel may frequently be seen under the front of these glaciers, but his impression is that they do not pass far under. There was, however, no opportunity of determining the actual case.

their further course then becomes a matter of the resolution of forces, dependent upon the mass and weight of the several glaciers and on the lines of least resistance, and these may be in the same direction as the natural lines of drainage, or may be in a direction contrary to or across those lines. Each case must be examined by itself, and its various conditions ascertained before it can be determined whether or not the conclusion is in harmony with all the postulates.

The moraine detritus, in the sense I take it, is not therefore the product only of the *moraine profonde* of AGASSIZ, but is the sum of all the débris carried down by a glacier and projected in its front, or subsequently ploughed up by the advancing glacier, and overlaid by the rolling stream of ice.* It is this which forms that unstratified mass of decomposed and ground-up rock, rock débris, angular fragments and pebbles, and subangular striated fragments—grey and argillaceous in this district, but varying, as is well known, in texture and colour in others, according to the nature of the local rocks—which so often lies upon the glaciated rock surface. It is to this sub-glacial product that I should restrict the term "Till," or else designate it as *land-till*.

Under the various circumstances here noted, the terminal moraines of separate glaciers may have remained isolated or have become confluent; may have been passed over by the ice, or pushed indefinitely forward; or they may have been piled or heaped up between conflicting glaciers. These several contingencies will, I think, account, more readily than would subsequent partial denudation, for the many otherwise inexplicable positions in which the moraine detritus is met with—in the valleys, on the sides of hills, and on the top of passes; wherever, in fact, the advancing glaciers have filled valleys, have been forced up on to higher ground, or have anywhere met and contended. The result of this has been, that generally in the narrower and in the steeper valleys, where the ice-flow was little impeded, the moraine débris has been swept forward and removed; that in the broader and flatter valleys it has been left in isolated patches and ridges at various levels, while in the larger plains it occurs in more continuous and extended sheets.† The same causes would, in some places, produce contortions in the Till, and in others would press it out into great lenticular masses.

In the Spean Valley, moraine detritus forms mounds at intervals all down the valley, but their character is much masked by subsequent water action, owing to which they are covered with gravel and often levelled on the top so as to form terraces. The large accumulation of this débris in front of Glen Treig, and at the entrance of the Rough Burn Glen, I attribute to the arrested glacier action resulting from the meeting of the glacier from Glen Treig with the one descending from the glens on the opposite side of Strath Spean; while the terraces fronting these and the Gulban mound

* It is in this wider sense apparently that the term *moraine profonde* is used by HOGARD and DOLFUSS-AUSSET; but as that term is generally understood in AGASSIZ's more contracted sense, its use geologically seems to me objectionable.

† This would explain the difficulty, alluded to by various writers, that arises from the absence of glacial moraine detritus in many highly glaciated tracts of the Highlands.

I take to be due to this moraine detritus, planed down at its lower end by water action at the lake period or during the escape of the lake.

The general character of some other moraine terraces may be seen in pits on the side of the road between Spean Bridge and Roy Bridge ; at places N.E. of Roy Bridge; near Murlaggan, and elsewhere. The following section of one is on the side of a burn (476 feet above the sea), about half a mile west of Murlaggan, where the footpath leads across the hills to Bohenie :—

Fig. 6.

Section on north side of the Spean Valley between Achluachrach and Murlaggan.

a. Coarse gravel formed of reconstructed moraine débris, about 15 feet.

m. Moraine detritus (Till) of the Spean Valley, about 60 feet.

In Glen Roy, between Bohuntine and Achavady, the moraine detritus rises on both sides of the valley to 200 or 300 feet above the river (there 400 to 500 feet above the sea), which has cut its way through it. It consists of a light grey, unstratified sandy clay, full of angular fragments and blocks; that it has once been higher is indicated by the reconstructed mass of stratified gravel of the same materials overlying it. Before its partial denudation it could not have been much, if at all, below the level of the lowest of the parallel roads. A like deposit is mentioned by Mr. MILNE HOME* at the entrance of Glen Collarig, forming a cliff 300 to 400 feet high of grey "boulder clay," rising above the highest "road." These moraine beds are, I consider, due to the meeting and consequent block of the Glen Roy and Glen Collarig glaciers with the great mass of ice in Strath Spean, and cannot be looked upon as remnants left after denudation of a larger area so much as original local accumulations. (See Map, Plate 46.)

The large terrace mound of the Turret and the smaller ones lower down Glen Roy I look upon in the same way as glacier débris levelled and gravel-covered by subsequent water action in connexion with the glacier lakes. This would account, which the other theory does not, for the absence of "Deltas" to the upper "Roads."

Between Spean Bridge and Fort William is the conspicuous mass of sand and

* Trans. Roy. Soc. Edinb., vol. xxvii., p. 603.

gravel, forming Unachan Hill, which rises to the height of 613 feet. I traced moraine detritus up to the northern base of the hill.*

While these sub-glacial Till deposits were being formed under the ice at various levels, the continued extension of the ice-sheet carried other débris, boulders, and gravel on its surface to higher levels. The rolled gravel may have been formed by rivulets flowing off the mountain sides and discharging on the ice-sheet, or by streams on the ice-sheet itself; or it may have been older gravel from a distance. What, however, may be the origin of some of the well-rounded pebbles found on Craig Dhu, and of those mentioned by Mr. MILNE HOME as occurring on the hills around Glen Gluoy at heights of from 1,700 to 1,800 feet, has yet to be determined.

These questions respecting the conditions of the ice-sheet of Scotland are necessarily somewhat speculative, but in our ignorance of the effects produced by the great ice-sheet of Greenland, we can only draw our inferences from the residual phenomena in districts once similarly covered; and I submit these observations as indicating probable causes of general application and as indices for further research.

§ 9. *The Level of the Land at the Incoming of the Glacial Period.*

In speaking of the ice-sheet we have considered it only in reference to the levels of the country as they at present exist; but when we reflect on the great changes which the country has undergone since the early glacial period, we cannot suppose the existing levels to be identical with those which obtained at that time. The submergence of the land to the extent of from 1,300 to 1,500 feet, succeeded by movements of elevation of equal or greater importance, which we know to have taken place in the later glacial times, renders it impossible to imagine a return now to the *status quo ante* of the earlier period; and it is almost equally difficult to suppose that the relative levels of distant, or even of nearly adjacent, areas can have been maintained.

The question, therefore, arises whether the land stood lower or higher at the insetting of the glacial period. The observations of Mr. JAMIESON show that, immediately prior to it, the east coast of Scotland stood at a lower level, for he has found beds, which he considers to be of the age of the later Crag deposits, skirting the coast of Aberdeenshire at a height of about 200 feet.† These beds, however, extend only a few miles inland, and no similar deposits have been met with on the west coast. On the contrary, there are grounds for believing, from the occurrence of mammalian remains of pre-glacial date, that at about that time part if not the whole of the west coast was dry land. Great Britain and Ireland in all probability constituted part of the continental area; and the existence of ice-striæ, not only in inland valleys and hills, but likewise horizontally along hills and slopes facing the sea, indicating the movement

* Post, p. 715.

† Quart. Journ. Geol. Soc., vol. xxi., p. 162.

of a body of ice in the present sea-channel, renders it almost certain that the land at this period extended much further westward into the Atlantic area.*

Mr. R. A. C. GODWIN-AUSTEN† so far back as 1849 came to the conclusion, on evidence of an entirely different order, that the bed of the English Channel "was in the condition of dry land previous to its occupation by the waters of the pleistocene sea, or during the period of the pliocene (crag) accumulations of the German basin, and that, together with a large area beyond, it served to connect the British Islands with France on the south, and Ireland on the west, into a tract which had a far greater amount of elevation than any portion of it has at present" (p. 94); and further, he remarks that "the period of the terrestrial conditions of greatest cold over the area of Great Britain would therefore be, when it was part of an area, of much greater extent, and at a much greater elevation" (p. 95).

He shows that there is not only evidence of a marginal line of coast at depths of from 50 to 60 fathoms, but there is also on the western slope of the Little Sole Bank, where the sea bed falls rapidly from the 100 to the 200 fathom lines, evidence of a still greater former elevation, in the fact that on these slopes large perfect, though decayed, shells of littoral species, such as *Littorina littorea*, *Patella vulgata*, &c., and *shell-sand* are found, whence he infers "that we have at this place the indication of a coast-line of no very distant geological period, buried under a great depth of water, and removed to a great distance from the nearest present coast-line."

On the west coast of Scotland the excessive glaciation of all the sea lochs and islands point to the westward flow of the great ice-sheet, descending from the watershed of the Ben Nevis and other mountain ranges of the Highlands, over ground then above the present sea-level, to a more distant sea; and both Professor A. GEIKIE‡ and Dr. J. GEIKIE§ have argued from several considerations, and especially from the contours of the sea-bed between the Scottish, North of England, and Irish coasts, that there is reason to infer the surface even far "under low-water mark has been dressed and moulded by the ice-sheet;" that the bed of the Irish Channel was then above the sea; and that the country stood considerably higher above the sea than now—a height estimated by the latter at not less than 600 feet.

I am, however, disposed to think with Mr. GODWIN-AUSTEN that the old coast-line may more probably have been nearer to the 200 fathom contour, as, so far, the levels are regular and continuous; but beyond that line the soundings suddenly become very deep and irregular. He sees in the slopes lines of old land escarpments (p. 86).

The map which accompanies Mr. GODWIN-AUSTEN's paper shows also that the

* In addition to the cases mentioned by other observers, I have found ice-striæ running horizontally along the face of the hills fronting the sea near Harlech, and again at the extreme south-west point of Wales similar striæ may be seen running (S. 17° W.) out to sea at Whitesand Bay, near St. David's.

† Quart. Journ. Geol. Soc., vol. vi., p. 69.

‡ *Op. cit.*, p. 96.

§ 'The Great Ice Age,' 2nd edit., p. 292.

sea-bed at the entrance to the Irish Channel is strewed in places with fragments of granite, while on the slopes of the Little Sole there occurs a débris of "large angular and rounded granite." Supposing that one section of the great North British glaciers or ice-sheet descended the bed of the Irish Channel, is it possible that it may have extended so far as lat. 49° N. and long. 10° W., and that this angular granite may be old glacial débris, or that in the Little Sole and adjacent banks we have remaining the moraine heaps of the old ice mantle?

The wide range of the ice-flow from the Scotch and North of England mountains as centres would also seem to indicate that the elevation of those areas was then relatively greater than at present to the surrounding areas.

There is, therefore, some reason to believe that at the inset of the glacial period the land of Scotland may have stood not less than from 1,000 to 1,200 feet higher than now, and, for all indications to the contrary, that height might even have been considerably more.

If, however, the extent of the elevation of the land at the commencement of the glacial period be somewhat uncertain, owing to the difficulty of precise proof in such cases, there is no such uncertainty respecting the submergence that succeeded the first period of glaciation, the extent of which we are enabled, in consequence of the different nature of the proofs, to measure with some degree of certainty.

§ 10. *The Effects of the Subsequent Submergence on the Climate and on the Ice-sheet.*

It has been clearly established, on the evidence of fossiliferous marine beds, that after the first great glaciation of the country, the south of Scotland was submerged to the extent of 500 to 600 feet or more; while in northern and central England, Wales, and Ireland the submergence is proved, on the same evidence, to have been not less than 1,300 to 1,500 feet. There is, however, no similar proof of the submergence having been of like importance in the north of Scotland or in the south of England. In Aberdeenshire* Mr. JAMIESON has shown that the beds of this period of submergence do not extend higher than 300 feet. In Banffshire† I have found them at a height of about 250 feet; while in the district between the latter place and Lochaber they have not been recognised at greater elevations than about 100 feet—viz.: at Ardersier, near Fort George.‡ Still further north, in Caithness, a shelly boulder clay extends to a height of 200 feet, but there is yet some difference of opinion as to its origin. On the west coast marine clays of this age have been described by Mr. R. B. WATSON in Arran§ at an elevation of 320 feet; in Bute they are formed no higher than 40 feet; while on the coast of the northern Highlands none have been

* Quart. Journ. Geol. Soc., vol. xxi., p. 170.

† Trans. Geol. Soc., 2nd ser., vol. v., p. 146.

‡ JAMIESON, Quart. Journ. Geol. Soc., vol. xxx., p. 321. Height not mentioned. In 'The Abstracts of Spirit-Levelling of Scotland' the height of the Ardersier Church above the sea-level is given at 87 feet.

§ Trans. Roy. Soc. Edin., vol. xxiii., p. 526.

found except close to the sea-level (the exact age of these seems uncertain); though in the islands of the Northern Hebrides there are shelly clays as high as 175 feet.*

We are not, however, to conclude on the negative evidence that the sea reached no higher than indicated by these fossiliferous deposits. Some of the sands and gravels at higher levels may be attributed to marine action. Even on the east coast fossiliferous beds are the exception, and Mr. JAMIESON has reasonable grounds for saying that "we are not entitled to say that the submergence reached no higher than 500 feet merely because marine fossils have not been discovered at great heights."†

The higher Raised Beaches on the west coast afford corroborative evidence. No shells have been found in them, but this might be owing to the exposed nature of the coast or to the shells having been dissolved out. Their horizontal lines, and the perfectly well rolled large pebbles of which they are formed, leave no doubt of their origin. The lower 10 feet and possibly the 40 feet Beaches are of more recent date, and I do not now refer to them but to the higher terraces noticed by Captain VETCH,‡ Admiral BEDFORD,§ the Duke of ARGYLL,|| and Mr. J. F. CAMPBELL,¶ which are in all probability of glacial age, and may belong to this intermediate period of submergence. They are very distinct on the west coast of Jura, where the Duke of ARGYLL ascertained their heights by aneroid barometer to be respectively 50, 75, and 125 feet above present sea level, while some in the distance appeared to be higher. Further north he thinks they have been traced to the level of 160 feet.

Assuming the submergence in the Highland district to have been only 400 to 500 feet, if we add to this the greater height of the land at the period of previous glaciation, it would, on Dr. J. GEIKIE's estimate of about 600 feet, or of my own of 1,200 feet or more, establish a difference of not less than 1,000, and possibly of more than 2,000 feet, in the height of this part of Scotland between the two periods we are considering.

This difference of level would produce a two-fold effect upon the climate: 1st, that resulting from altitude, which allowing 1° Fahr. for every 300 feet of elevation, would be equal to a change in mean temperature of from 3° to 6° Fahr.; 2nd, that caused by the conversion of a continental area into an archipelago. This last would have a much more sensible effect on the temperature, for the Highlands of Scotland became, in consequence of this subsidence, surrounded by an open sea, with only the higher peaks of Ireland, Wales, and the North of England above the waters, so that the warm currents of the Atlantic reached the foot of the Highland mountains, and penetrated deep into the land—a result which could not have failed to bring about a very important amelioration of climate, possibly to the extent of from 9° to 10° Fahr., or may be more.**

* J. GEIKIE, Quart. Journ. Geol. Soc., vol. xxxiv., p. 863.

† "Last Changes in Scotland," Quart. Journ. Geol. Soc., vol. xxi., p. 177.

‡ Trans. Geol. Soc., 2nd ser., vol. i., p. 416.

§ Quart. Journ. Geol. Soc., vol. ii., p. 577, and vol. xii., p. 167.

|| Trans. Brit. Association for 1866, p. 86.

¶ *Op. cit.*, p. 9.

** The effect would be somewhat analogous to the removal of the seaboard from the west to the east of

The effects due to these two causes would certainly amount to a difference in the two periods of not less than from 12° to 15° Fahr., which is equivalent to the difference now existing in annual temperature between London and the south coast of Spain or of Sicily, and to more than exists between St. Petersburg and Paris.*

There is also to be taken into consideration the increase of heat consequent on the gradual diminution of those intense glacial conditions†—holding the cause not to be entirely physiographical—which has ended in our present climate.

Supposing the subsidence to have been slow (though there is no reason to suppose that it was at all so slow as that of Scandinavia or Greenland at the present day), and that the sea crept gradually and quietly over the land, slowly floating away the ice covering the submerged parts, there would have ensued a gradual and steady rise of temperature raising the level of the snow-line, and resulting in a steady and continuous thaw. The great ice-sheet of Scotland, with its frequent small gradients, conflicting elements, and its many projecting mountain ridges, must at this time have presented a surface of great irregularity. The water would, as the thaw proceeded, collect in pools and ponds, and, in the absence of existing water channels, would there remain until the further progress of the thaw levelled the obstacles presented by the uneven surface of the ice, and allowed it to escape either by the wear of channels on the surface or by crevices in the body of the ice, which however from the small gradients and the pressure in the main valleys must have been generally too compact for the latter purpose. Such ponds and lakes are, in some places, where glaciers descends into warm valleys below the snow-line, of not uncommon occurrence, and under certain circumstances lakes of considerable size are thus formed.

In glacier districts there are four classes of lakes—the first are those formed by the greater glacier of a main valley crossing, at some distance below the snow-line, the entrance of lateral valleys, the streams in which they thus dam back; the second by the smaller glacier of a lateral valley traversing the main valley and forming a barrier to the head waters of a river; the third by water accumulating in hollows on the surface of the glaciers themselves, and there forming pools and small lakes; and the fourth those where streams have been dammed back by old terminal moraines. With this last description of glacial lakes we are not at present concerned.

In the first class of lakes, of which the Merjelen See is an instance, the water escapes from time to time with greater or lesser rapidity through fissures in the glacier, leaving the barrier otherwise intact and soon again available; the second class gives rise to

Scandinavia. The difference in the winter temperature of Bergen and Stockholm, which are nearly in the same parallel of latitude, is, according to DOVE, 10° 28′; while the relative difference in the winter and summer temperatures of these places is 21° 28′ and 34° 39′ Fahr.

* Comparing the winter temperature of Scotland (taken at 38°) with that of Greenland (taking the mean between Lichtenau in 60° 31′ N. lat., and Upernivik in 72° 48′ N. lat.), they are as 38° to 5° Fahr., or a difference of 33°; but the mean annual temperature of Greenland, taken in the same way, gives 23°, and that of Scotland about 47°, or a difference of only 24°.

† None of the reasons hitherto assigned for these conditions are to my mind satisfactory.

larger lakes which end by bursting and sweeping away their barriers, when they produce the most devastating effects, as in the instances of the Skardo and the Drance inundations; of the third class we know little, as they are rare, and the scale on which they occur in Europe is comparatively insignificant. In hot seasons there may be here and there a few temporary ponds formed on the ice, but as a rule it is only in countries in which the glaciers descend into valleys where the summer heat is considerable, that we find these large glacier lakes of this description.

In the Alps this latter class of lakes is met with on a few of the glaciers in the form of pools, generally small (baignoires, of AGASSIZ); still some of these attain the size of from 20 × 20 metres to 20 × 40 metres. They move with the glacier, and drain sometimes suddenly through fissures while at other times they last for years. A remarkable one attaining the dimensions of a small lake has been described by DOLFUSS-AUSSET.* It was noticed in 1842 on the Aar glacier near the confluence of the Thierberg glacier. It then had a superficies of 10 acres with a depth of 206 feet, and was surrounded by steep cliffs of ice over which glacier detritus was constantly tumbling and gradually filling up the lake. As showing how compact some glacier ice may be, this small lake lasted 24 years, and was carried a distance of 600 feet at a rate of about 25 feet annually.

In the Himalayas, lakes of this class are not uncommon. Sir JOSEPH HOOKER notices one part of the Kinchinjhow glacier, where it was half a mile wide and the surface very undulating ("like a troubled ocean"), which he found covered with large pools of water, one of which was 90 feet deep.†

But it is in the part known as the Mustakh range that these lakes are most numerous. In Colonel GODWIN-AUSTEN's account of that range many such bodies of water are described. On the Pumnah glacier,‡ where the surface is either a succession of ridges more or less stony, or where in other places it resembles "a sea of frozen waves," "small pools of emerald-green water" fill many of the hollows and are surrounded with cliffs of ice; in some parts there are streams of running water which often end abruptly by discharging down some crevasse. On the Bahio glacier there are hollows filled with water forming lakes often as clear as crystal, and of great depth. Some of these lakes measured as much as 500 yards in length and from 200 to 300 yards in breadth, and were spread over a distance of more than 2 miles along the centre of the glacier which was there very level.§

First, deep hollows and then lakes are formed by the damming back of the glacier streams. The barriers between the lakes are constantly giving way, so that the lakes

* *Op. cit.*, vol. v., p. 460.

† 'Himalayan Journals,' vol. ii., p. 134, 1854.

‡ Journ. Roy. Geogr. Soc., vol. 34, p. 31.

§ Ibid. p. 38. Colonel GODWIN-AUSTEN informs me that on the lower part of the Baltero glacier, the long parallel moraines get arrested in their course, and run one into the other, and thus form stony barriers.

present very changing outlines and dimensions. The following is an ideal sketch, by Colonel Godwin-Austen, of one of these lakes :—

Fig. 7.

a. Lakes. *b.* Moraine débris. *c.* Glacier ice. *d.* Ice cliffs.

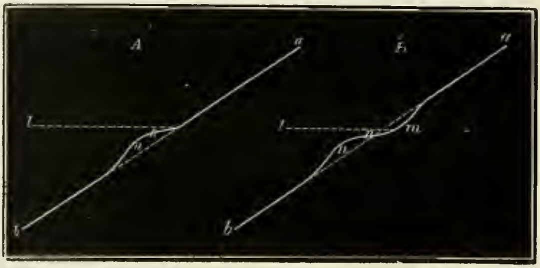
We can therefore imagine that, under the effects of the continued thaw, the old ice-sheet of Scotland became covered with pools and lakes, which would go on filling until the water reached the lip of the basin, when the surplus waters would escape along the natural lines of drainage, either on or beneath the ice, to some lower levels; but when, owing to exceptional circumstances such as those which prevailed in the Spean and Roy Valleys, the ice had been heaped up in larger masses so as to raise high the water-level, then these lakes, dammed back pending the removal of the barriers, made their temporary outflow over any cols lying at a lower level than the barriers and leading into adjacent valleys free from such blockages.

So while every mountain side was contributing its rills and rivulets to innumerable temporary pools and tarns on the melting ice, their waters were, in such instances as those presented by the Lochaber Valleys, retained, and formed lakes ultimately extending the length and depth of the glens. If there were no passes at levels lower than the barrier at the entrance, then the lake would go on unceasingly filling until the water overflowed the barrier itself, or burst a passage through it, in which case, as no permanent fixed water-level had been established—for after the first overflow the barrier would be speedily destroyed—the waters, draining off at once, would have left little or no mark of their presence on the hill sides.

In Lochaber, however, the main barriers were of such height and permanence, and the cols were so placed, that the waters found earlier outlets over the latter than was practicable through the former, and they thus obtained, at successive intervals, fixed and definite levels. I believe that to these conditions the levels or lines of the parallel roads are owing; but I further believe that it was not, as commonly held, by length of time and long continuance of the same water level that the "roads" were actually shaped, but by the sudden discharge of the water on successively breaking through minor barriers at each col.

There are, no doubt, shore beaches formed by the other classes of lakes, but as they have the ordinary origin I do not think it necessary to discuss them here. The more or less permanent lakes, formed in lateral valleys by main glaciers, have in many cases given rise to such shore lines. The structure of these shingle ridges is, however, very different to that of the Lochaber "roads." They are formed by the soil and rubble, carried down the hill sides by the rain, rivulets, or frost, and spread out by the water, as in A, fig. 8, or aided by the erosion of yielding slopes, as in B, and form in both cases projecting shelves having slopes *n* greater than those of the hill-sides *a b*.* Several illustrative instances of these glacial lake-beaches will be found mentioned in the works before referred to.

Fig. 8.



a, b. Slope of hill. R. Shore-line or beach. *m*. Indent produced by erosion. *n* (*B*). Débris removed from *m*. *n* (*A*). Débris fallen from the slopes or heights above. *l*. Lake level.

§ 11. *Structure of the "Roads:" their Inclination to the Horizon.*

The "roads" are, it is well known, composed of perfectly angular fragments derived from the local rocks (mica-schist, micaceous and clay slates,—and granite at the head of Glen Roy), with a few rounded pebbles derived in part from the sand and gravel spread over the hills by the previous ice-action, or else formed on the spot by the rivulets and torrents running down the hill sides. The wear, therefore, of these pebbles is due to other and anterior causes, and the angular fragments alone indicate the amount of wear attendant upon the formation of the "roads." It is clear that there was none of any moment—none showing long shore wear.

According to the few positive data we possess, the slopes of the hill sides above and below the "roads" vary at different places from angles of about 23° to others of about 35°.† MACCULLOCH, who gives the angles of the "roads," is silent in respect to those of the slopes, the angles given in fig. 9 being only taken by measurement from his outline diagrams of the "roads." In Mr. BROWN's section of the lower Glen Roy "road," he found the angle of the slopes (measured with a clinometer) to be 25°. The Ordnance Survey have, however, determined the exact slopes at a few places in Glen Roy, for the following table of particulars of which I am indebted to Colonel PARSONS, R.E., of the Ordnance Department, Southampton. The references are to the 6-inch Ordnance maps.

* See Sir CHARLES LYELL's figure of the beach of the Merjelen Lake, which resembles fig. 8, B, in general characters.—'Principles of Geology,' 10th edit., p. 377. There are also beaches in some valleys which have been old sea lochs.

† In one case it is given as only 19°.

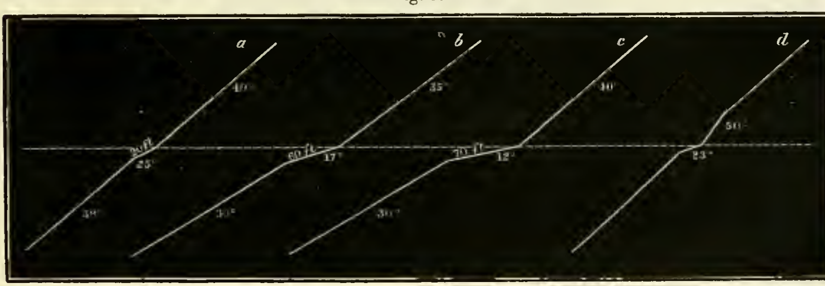
Table I.

Angles of inclination to horizon of slopes above and below parallel roads of Glen Roy.

Approximate height of roads.	At point above road N. of Glen Roy River, near N. edge of sheet 127.	Ditto.	Ditto.	At point below road N. of Glen Roy River, near N. edge of sheet 127.	Ditto.	Ditto.	At point above road S.E. from Burun Farieunn Δ, S.W. side of Glen Roy River, sheet 112.	Ditto.	Ditto.	At point below road S.E. from Burun Farieunn Δ, S.W. side of Glen Roy River, sheet 112.	Ditto.	Ditto.
feet	°	°	°	°	°	°	°	°	°	°	°	°
1,148	..	..	33	..	..	35	..	..	19	..	..	36
1,067	..	34	..	..	31	..	..	23	..	..	22	..
850	31	..	..	28	..	..	26	..	..	26	..	..

According to Macculloch, the "roads" vary from 50 to 70 feet in width; but Sir H. James gives them 40 to 50 feet. They are not flat, being, according to the former, only inclined at angles of from 12° to 20° and even 30° to the horizon. The following are some of his sections, with the addition of the estimated angles of the slopes.

Fig. 9.



Sections of the "roads," figs. 3, 2, 4, and 7 of Macculloch.

Macculloch says of these that *a* occurs only near the rocky places at top; *b* is a form which occurs in many places; *c* occurs at the entrance of Glen Gluoy and elsewhere; and *d* gives the exceptional case of an upper talus, met with in one place only.

In Mr. Brown's section the angle of the "road" is only 11°. The Survey measurements, for which I have also to thank Colonel Parsons, while they confirm Macculloch's observations, somewhat extend the range of variation, and they further give the spot where the observations were made, which Macculloch omits.

TABLE II.

*Approximate angles of inclination to the horizon of cross sections of the parallel roads of Glen Roy taken at various places.**

Approximate height of roads.	On road S.E. from Beinn Jarunn Δ, S.W. side of Glen Roy River, sheet 112.	Ditto.	Ditto.	On road E. from Glen Roy River, at S.E. corner of sheet 112.	Ditto.	Ditto.	On road S. of Gleann Glass Dhorii, sheet 127.	On road N. of Gleann Glass Dhorii and E. of Glen Roy River, sheet 127.	On road W. of Glen Roy River, sheet 127.	On road S.E. from Beinn Jarunn Δ, S.W. side of Glen Roy River, sheet 112.	On road W. of Glen Roy River, near N. edge of sheet 127.
feet	°	°	°	°	°	°	°	°	°	°	°
1,148	15	..	..	10½	..	..	..	..	..	29	..
1,067	..	8½	..	..	17	..	5½	8 to 12	10 to 19½	..	..
855	..	..	19	..	..	6½	5	5 8	..	..	25½

From this it appears that the gradients of the "roads" vary from 1 foot in 11 to 1 in 2, and that there are places where the angle of the "roads" is as great as that of the slopes, but this may be at places where the rock comes to the surface.

As MACCULLOCH remarked, the "roads" "bear the resemblance of parallel layers applied in succession to the side of the hill," and there is no instance (with the one exception of *d*, fig. 9--his No. 6) of a superior, and none at all of an inferior talus. This describes them with sufficient accuracy, although the parallelism is subject to some variation and is rarely exactly uniform above and below the "roads."

The importance of this feature has been overlooked by subsequent observers, with the exception of Sir JOHN LUBBOCK,† who showed that with such a structure it was impossible for the "roads" to have been formed either by erosion or by the heaping up of the materials by wave or water action, in accordance with the theories hitherto held. In the one case he contends that a notch or sub-cliff, and in the other a prominent ledge would be formed. Nor can the notion of continuous deltas be admitted, as the shelves in that case ought to be broadest where rivulets came down the sides of the hills, or where the melting snow brought down most detritus. But the "roads" exhibit no such irregularity of outline.

Sir JOHN LUBBOCK is of opinion that the parallelism of the slopes is due to a slight wave action on the loose materials which covered the hill sides, and which was accompanied by a re-adjustment of the débris at the original angle of repose ; but this

* Two measurements of Glen Gluoy "road," "on road from Lieter Finlay Δ, W. side of Glen Gluoy River, sheet 112," give respectively inclinations of 20° and 15°.

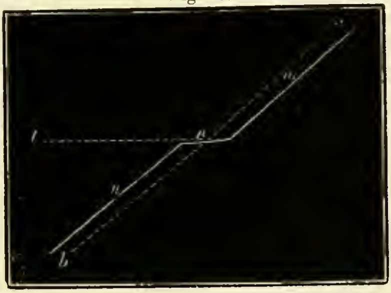
† Quart. Journ. Geol. Soc., vol. xxiv., p. 83, 1868.

explanation would seem to me to involve a greater uniformity and a higher angle on the slopes than actually exists.

I cannot, in fact, see that any theory of wave action will enable us to explain the phenomena. If the original slope *a*, *b*, of the hillside were, as in fig. 8, B (p. 696), less than that of the angle of repose of the detritus, the wear of it by wavelet erosion would, as the materials were gradually removed, give rise to a slope at *m* greater than that which existed above beyond the reach of the fall, while the débris falling from *m* into the lake *l*, would equally, as they were carried over the shelf R, form at *n* a slope which would also be that of the angle of repose; and that being the same in water as in air, the slope of *m* would be the same as that of *n*, and greater than that of the line *a*, *b*. But with one or two local exceptions, no such indent as *m* exists, and nowhere does a ridge such as formed by *n* occur on any section of the parallel roads.

If, on the other hand, the line *a*, *b* (fig. 10) had been that of the angle of repose of loose detritus, the upper slope *a*, R, would, it is true, as it crumbled back on the removal of the débris by wavelet action, continue unchanged through *m*; while the

Fig. 10.



a, *b*. Original slope, taken as that of the angle of repose of loose débris. *m*, *n*. Slopes after transfer of portion of débris from upper to lower part of slope. *l*. Lake level. R. Shore line.

fallen débris, precipitated over the shelf R, would roll down on the lower slope R, *b*, at the same angle of repose as it had above, so that the fresh slopes *m* and *n* would be themselves parallel, and also parallel to the original slope *a*, *b*, and the theoretical parallelism of MACCULLOCH might in this way be obtained. But here again it is to be objected that the slope *a*, *b* is never that of the uniform slope of loose detritus, but a variable slope having angles with the horizon, ranging, as shown in Table I., from 19° to 36°, all of which are less than that of the angle of repose of débris of this character. We have in the detrital mounds of the Turret a measure, or a closely approximate measure, of what this angle is. There, where the mound has been worn back by the Roy, the loose angular and subangular fragments of the upper beds, which are composed of very similar materials to those covering the hill sides, have fallen down and form sloping banks of which the angles vary very little from 40°, which is greater than any of the recorded angles.

Nor is the variable inclination of the "roads," shown in Table II., in accordance with the view of their being shore margins. Wherever, on the shores of lakes or seas, the slopes below water are comparatively uniform, the strand between water marks also presents a surface having a more uniform gradient than obtains in the "roads."

Nor could the irregularity in the inclination of the "roads" occur on the shore of a lake or a sea, combined with the regularity in their width which generally exists. Steep inclines of the strand would indicate steeper slopes below water, and steeper slopes below water would be accompanied by contracted width of shore line.

Any erosion or shore-line hypothesis would also involve an interior structure of the "roads," showing the small successive increments made from year to year to the shelf R, in a manner analogous to false bedding or oblique lamination, and this has not been shown to exist.

These objections seem to me to be fatal to the idea that the "roads" are due merely to the long-continued action of water on a shore-line. There is, nevertheless, a symmetry and uniformity of character about the "roads" which indicates some general cause, one independent of local conditions, which are subordinate to it, and of magnitude sufficient to give a common impress to the whole.

§ 12. *Origin of the "Roads."*

In the case of the 1st, 2nd, and 4th "roads," we do not know what the conditions immediately antecedent to their formation were; but in that of the 3rd we are in possession of these conditions, and are in a position to trace uninterruptedly the successive changes which took place from the finish of No. 2 "road" to the formation of No. 3 "road." If we find in this sequence an explanation that will account for the formation of "road" No. 3, its application to the other three "roads," which have clearly the same origin, will follow as a matter of course, provided the other conditions are concordant. We have therefore, for the present, to confine ourselves to "roads" Nos. 2 and 3, which restricts the inquiry to Glen Roy.

The height of No. 2 "road" has been found to be on a level with that of the col between the head of Glen Roy and Glen Spey, and that of No. 3 with the height of the col between the tributary Glen Glaster and Glen Spean. Therefore, as there is a difference of 76 feet between the height of the two cols, when the lake stood at the level of No. 2 "road," and its overflow escaped by the higher Spey col, the lower col of Glen Glaster must have been blocked by a barrier more than 76 feet high.

For the moment, it is immaterial to the question whether the barrier consisted of glacial detritus or of ice. It could be no other. Now it is well known that so long as a dam formed of gravel, soil, or clay stands above the level of a reservoir, it is secure; but if the water rises so as to trickle over the edge, then, unless the mischief is at once stopped, the water quickly enlarges its channel, and the velocity and power of the stream increase so rapidly that the dam is soon destroyed, and the water escapes with destructive speed. The Glen Roy lake having an established outflow into Glen Spey, there could be no rise in the water-level, but the slow weathering of the detrital barrier—or, what is more probable, the gradual melting of the ice-barrier—of Glen Glaster pass would be sure there to lead to, sooner or later, a catastrophe of this nature.

With what rapidity a small breach in detrital barriers enlarges and leads to such a result, was well exemplified by the Holmfirth flood. In that case, a reservoir with a superficial area of 11 acres, and 70 to 80 feet deep in the centre, had been formed by throwing across a valley a barrier 87 feet high, 16 feet wide at top, 480 feet at bottom, and 340 feet long, constructed of clay with a facing of gravel and stone.* A small breach was accidentally formed, and so rapidly increased, that the barrier suddenly gave way, and a portion, 140 feet wide at top and 25 feet at bottom, was carried away at one swoop, and the reservoir drained in a very short space of time. Similar rapid bursting of reservoirs, under like circumstances, have occurred in the neighbourhood of Sheffield, in works connected with the Crinan Canal, and elsewhere. In cases of slight overflow of river banks like results have followed, and the inevitable consequences of such accidents are well known to all engineers.

Nor, although we might fairly predicate what would be the effect of the bursting of an ice-barrier, are we entirely without evidence of the fact. In the first class of glacier lakes before described, the water escapes, sometimes quickly, at other times slowly, through fissures and crevasses in the glacier, which itself does not materially suffer. In the second class of larger lakes, formed by a glacier barrier transverse to the main valley, the barrier is carried away suddenly whenever the pressure becomes too great or an overflow sets in, and the water is discharged with resistless rapidity. One of the best-known cases of such casualties is that recorded by CHARPENTIER,† in which, in 1818, a glacier descending from a lateral ravine crossed the valley of Bagnes, and dammed back the small stream of La Drance. This soon formed a lake, which grew to be about 2 miles long and more than 200 feet deep at its lower end. In the summer the dam of ice gave way, and in *twenty minutes* the whole volume of water, estimated at 600,000 cubic toises, was discharged. The ground covered by the lake suffered little or no change, except near its outlet; but the torrent spread destruction as far as the valley of the Rhone.

In 1844, Dr. FALCONER‡ drew attention to a great flood which took place in the valley of the river Lundaye (a tributary of the Indus), and swept away innumerable villages; while at Attock, on the Indus, that river rose 30 feet above its usual level. The flood was supposed to have been caused by the rupture of a glacier from a lateral ravine, crossing the valley and damming up its head waters; but Mr. DREW, who has since visited the district, found that the barrier had been formed lower down, and on the

* Quart. Journ. Geol. Soc., vol. viii., p. 225.

† 'Essai sur les Glaciers,' p. 204; and RECLUS, 'La Terre.'

‡ "On the recent Cataclysm of the Indus," Journal of the Asiatic Society, vol. x., part ii., p. 615.

main Indus, by a vast landslip caused by an earthquake.* He estimates the lake so formed to have been probably about 35 miles long by about 1 mile broad, with a depth at the lower end of about 300 feet. The whole was drained in a day.

Colonel GODWIN-AUSTEN mentions another great flood of the Upper Indus, which was caused by the Biafo glacier crossing the transverse valley of the Braldoh, into which it descended and abutted on the cliffs on the opposite side.† The river usually forces its way at the foot of the cliffs, although in places it is completely hidden by the ice; but its channel occasionally becomes entirely obstructed, when a broad expanse, extending several miles up the valley, is converted into a deep lake. When the waters break through their icy barrier, more or less of it is swept away, devastating floods ensue, and the lake is in a very brief space of time emptied of its contents.

Some instances of the bursting of such glacier lakes are also recorded by Mr. DREW. The most important was the lake formed in 1850 by the advance of the Tarshing glacier across the valley of the Astor, till it abutted on the hill on the opposite side. At first the stream flowed under the glacier, but the passage becoming stopped up in that year, a lake was formed $1\frac{1}{2}$ mile long by $\frac{1}{2}$ mile wide, and with an average depth of 100 to 150 feet, and an extreme one of 300 feet. The water, on reaching the top of the barrier, burst through and escaped between the ice and the rock on the side, producing a disastrous flood which lasted three days. A point of interest to us in connexion with this glacier, as bearing upon the compactness which the ice-sheet must have acquired in the narrow pent-up Highland valleys, is mentioned by Mr. DREW. The glacier, which has now advanced again only part of the way across the valley, is so much crevassed that it is difficult to find a road over it; but when it abutted against the opposite hill, the crevasses were closed up, and the glacier was so smooth that people used to walk and ride on its surface.

It is very different with the discharge of lakes of lateral ravines abutting on the great glacier of a main valley. The discharge, though often quick, is at other times prolonged. A case is recorded by Mr. DREW of a lake of this description, $\frac{1}{4}$ mile long, 300 yards wide, and 150 feet deep, which took three days to drain;‡ while another, noticed by Colonel GODWIN-AUSTEN, 2 miles long by $\frac{1}{2}$ mile broad, after lasting a year and a half, subsided gradually, and took a month to drain away.§

It is not, however, with the destructive effects of the inundations caused by glacier lakes|| that we are at present concerned. The questions we have now to consider are the effects that would be produced within the area of the drained basin itself by the rapid discharge of the water; or in our case what, in an area recently exposed and

* 'The Jummoo and Kashmir Territories,' 1875, p. 417. See also VIGNE's 'Travels,' vol. ii., p. 362.

† 'Glaciers of the Mustakh Range,' p. 45.

‡ *Op. cit.*, p. 369.

§ *Op. cit.*, p. 48.

|| With regard to some analogous phenomena in connexion with the old ice-sheet, see JAMIESON in Quart. Journ. Geol. Soc., vol. xxx., p. 317, 1874; and 'The Great Ice Age,' pp. 230 and 231.

the bare surface not yet protected by vegetation, would be the result on that surface, —placed under water by the temporary conversion of certain valleys into lake basins, —by the sudden discharge of successive portions of the water through cols at different lower levels ?

In the absence of any conspicuous detrital remnants on Glen Glaster col, we may assume that the barrier was formed wholly or chiefly of ice—a remnant of the old ice-sheet due to the accumulation of ice by glaciers descending the glens of Ben Mheirlich (2,994 feet), and other hills immediately at the head of Glen Glaster. The barrier must have been one of considerable magnitude—high enough not only to dam the pass when the lake stood at the level of No. 2 "road" and flowed into Glen Spey, but also to have barred the passage when the lake, before it escaped over the col at the head of Glen Roy, had the yet higher level required on our hypothesis.

After a time, and for the reasons and in the manner before mentioned, this barrier—unsupported on the Glen Spean side, where the thaw had already begun to form the Spean Valley lake and had removed much of the ice in the lower levels—gave way, I conceive, suddenly, and was followed by a rapid partial discharge of the lake waters.

If we consider the condition of the surface of the ground at the time this took place, we find it recently relieved from its mantle of snow and ice, and the hills covered with a coating, several feet thick, of local angular fragments mixed with sand and clay, the result of decomposition, and, here and there, of moraine matter, sand and gravel, the product of the great ice-sheet and of the intense cold on the underlying rocks. As the ice disappeared this débris remained bare and exposed, and without any layer of vegetation to protect it from shifting from very slight causes.

Under these circumstances the detritus on that portion of the slopes, over which the water had risen in the enclosed valleys, became saturated with water, forming a soft yielding muddy and stony mass. As the lake fell rapidly, and exposed this detrital bank, the saturated mass of débris would part with its water, which, as it drained away, must have caused a loss in volume that led to the displacement of its diverse component parts, and thereby set the whole semi-liquid mass in motion, and caused it to slip or slide down after the falling waters of the lake, with a velocity in proportion to the angle of slope and momentum of the mass. The slide would continue so long as the escape of the lake waters continued, or until their level fell to the level of the Glen Glaster col. As these waters came gradually to rest, their inertia, opposed to the momentum of the detrital mass, combined with the absence of any fresh exposure and the cessation of the original cause of movement, more or less suddenly arrested the sliding mass, deflecting it in a direction more horizontal and outwards from the face of the hill, and thereby causing it to form a shelf parallel with the water-line :—the extent both of the deflection and the slide depending on the relation between the volume of the detrital matter and the angle of slope, and according as these varied so would the inclination of the shelf (or "road") to the horizon, and its precise parallelism with the horizontal water-line, also vary.

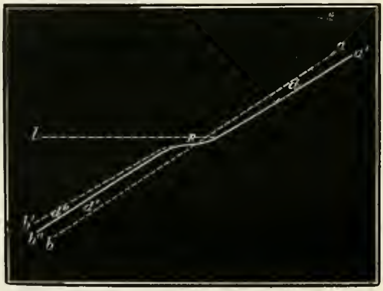
The question involves the consideration of the angle of repose of detrital matter under different conditions. If the detritus consisted only of angular or sub-angular débris, the angle of repose, whether in air or water, would vary within the limits of from 35° to 48°, or, considering the proportion of perfectly angular débris, it would in this case more probably be about 40°. But the matrix of the detrital matter consists of sand and clay, of which the angle of repose, when dry, is from 21° to 37°, and when saturated with water as low as from 14° to 22°. The angle of repose of the combined soil and stones would therefore depend on the relative proportion of the several materials, and on the amount of saturation.

Therefore the angle of repose of the mass of detritus set in motion would, as the water drained from it, tend to become greater; and as an equilibrium was established, commencing on the upper part of the slope first left uncovered, that part would be gradually stayed, while the portion, on the contrary, which continued to slide would, on the lake coming to rest, bulge forward at the water-level, where it had its maximum saturation, at a minimum angle of repose.

Owing to the variable nature and proportions of its elements, the problem is a very complicated one. The angles of the detrital slopes between the "roads" are, in fact, dependent both on the gradients of the underlying rock surfaces, and on the above-mentioned varying conditions of the detritus; while the angle of inclination of the "roads" is dependent on the combined effects of an arrested slide, and a simultaneous change of the state of equilibrium in the falling detrital mass, above and below the water-line.

The effects of these slides is represented generally in diagram fig. 11.

Fig. 11.



a, *b*. Original detrital slope.

a', *b'*. Slope after slide of detritus *d* to *d'd''* and fall of lake to *l*.

a, *b''*. Further modification of slope after another fall of the lake and slide of *d''*.

R. Shelf or "road." *l*. Lake level.

I do not suppose, however, that the present inclination of the "roads" is exactly that of the slipped detritus, but that the subsequent fall of débris from the slope above, caused by the action of winter snow and weathering,* which continued for a time afterwards, has formed a coating (*b*, fig. 14) that partially modifies the original angle.

As the lake again fell to the next level, the slope below the water-level would undergo further modification, as, in consequence of the detrital bank being then again set in motion, another slide would commence at the water-level, and carry down a portion of the detritus on this slope to a lower level, either to form another shelf if the waters received another check, or *en masse* to the bottom of the valley if no check occurred and the lake were drained. In fig. 11, R b'' represents the slope formed on the second or subsequent lowering of the lake-level, by the slide of this segment d''.

On those short portions of the "roads" over which I walked I met with no natural section, excepting one 4 feet deep in angular débris and clay; and the only published section I know of is the one which accompanies an interesting paper by the Rev. THOMAS BROWN, describing the discovery of Diatoms in the interior of the "roads."† Fig. 12 is a reduction from the original woodcut accompanied by the author's description.

Fig. 12.

Section of the lowest terrace ("road" No. 4), Glen Roy.

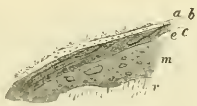
a. Humus, 8 inches to 1 foot. *b*. Stones with clay, 2 to 3 feet.

c. Finely stratified sand and clay, 3 to 8 inches. (Diatoms found in centre of bed.)

d. Clay with boulders indistinctly stratified with thin layers of sand going down to rock (*r*), about 20 feet. (Diatoms found in this bed 10 feet below the surface.)

This section is situated about midway in the Glen and on its west side.

Fig. 13.



a. Humus. *b*. Gravel and sands (*c* clay ?) of the "road." *c*. Underlying gravels and sand.
e. Line of unconformity.
m. Clay with boulders, most of them small (boulder clay ?). *r*. Rock.

Another section‡ (fig. 13) discovered by Mr. BROWN on the opposite or east side of the valley, but whether of the 3rd or 4th "road" is uncertain, presents features somewhat

* This is the action which now takes place on the shore of the Merjelen See, and which has there formed the beach line. See also on this subject "Observations on the Parallel Roads of Glen Roy," by Professor BABBAGE, in the Quart. Journ. Geol. Soc., vol. xxiv., p. 273.

† Proc. Edinb. Roy. Soc., vol. viii., p. 337, 1874. In the original paper the underlying rock *r* is not shown. This addition, together with the unpublished sections figs. 13 and 16, are from notes kindly communicated to me by Mr. BROWN. In fig. 13 I have altered his *d* to *m*.

‡ This section not being taken with a view to publication, the beds and angles were not measured.

different. It is probable that *b* in this section represents *b* and *c* (a very variable bed) in fig. 12; and that *c* corresponds with the mass *d* in this other section, though it differs from it in some respects, owing probably to some variation of the detritus on the slopes above; while *m* (boulder clay of Mr. BROWN), fig. 13, is not represented in fig. 12, and is probably moraine matter left by the Glen Roy glacier, like the more exposed mass nearer Bohuntine. The line of unconformity *e* is a feature to be noticed.

The interpretation I would suggest for section fig. 12 of Mr. BROWN's, is, that *d* is the hill-side detritus, which slid down as the lake-level fell; *c* the sediment that subsided from the lake waters rendered muddy by the fall of the detritus; and *b* the subaerial débris, formed of fragments which afterwards, from time to time, fell from the slopes above before they became covered by vegetation. This would accord with Mr. BROWN's discovery of siliceous *freshwater* diatoms in *c* and *d*, and with their absence in *b*. The species, which were determined by Professor DICKIE, are—

Pinnularia viridis	found in	c and *d*.
Hemantidium undulatum . . .	,,	c and *d*.
Surirella panduriformis . . .	,,	*d*.
Diatoma vulgare	,,	c.

It is important to note that Mr. BROWN found no marine species, which further tends to disprove the marine hypothesis of the origin of the "roads."

On this view, the section of the Glen Roy slopes at the foregoing point on the 4th "road," fig. 12, would be represented by the following theoretical diagram. The

Fig. 14.

b. Fallen subaerial débris. *c*. Laminated clay (settlement from the lake waters).
d. Slided subaqeous débris. *r*. Underlying rock.

circumstance of the rock here forming a ledge is, I consider, a chance coincidence, due to the irregular surface of the rock—an irregularity arising from the nearly vertical position of strata of varying degrees of hardness, and tending to form steps or ridges on the weathered surface.

Both the inner and outer angles of the "roads" are always much rounded off, as shown in sections 11 and 14.

It is to be regretted that there are no sections of the upper "roads," but the annexed rough sketch, taken nearly in front and from the opposite side of the river (over which there was no passage at this point), shows broadly the position of the underlying rock, and the greater accumulation of débris at the bottom of the hill,

Fig. 15.

Section of the three "roads" exposed by a small ravine on the east side of Glen Roy, a short distance above Achavady. (The fissure as here represented is too wide.)

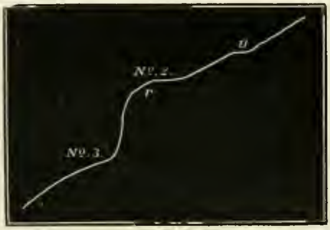
b–d. Undistinguishable gravelly débris. *m*. Moraine detritus or Till?
* Low cliff cut back by the river. *r*. Rock.

together with the presence at base of a grey argillaceous detritus, apparently Till or Boulder clay. The rock is here very near the surface—nearer, I imagine, than usual.

Fig. 16.

Near this spot Mr. Brown obtained the side view of the three "roads" shown in fig. 16. Above "road" No. 3 there is here the same indent (or superior talus, as it has been called) that Macculloch noticed in one other case. Fig. 17 represents a section I took on the slope of Tombrahn, at the junction of Glen Roy and Glen Turret, at a point where the upper "road" passes over a bare rounded ice-worn surface, *r*, of rock. At this place there are also faint traces of a higher road, *u*.

Fig. 17.



Section of the upper two "roads" in Glen Roy where they pass a protruding rock.

To return to the three "roads," Nos. 1, 2, and 4. We do not know what the conditions immediately antecedent to their formation were. In each case there is the essential col over which the water could escape, and in each case there is a like admissibility of a temporary barrier, such as the hypothesis requires, to dam back the waters of the lake until they rose to a height sufficient to overflow and destroy the barrier. Until this took place and a fixed water level was definitely established, the level of the lake would, for the reasons before assigned, be constantly varying, and although it might have left slight horizontal marks or lines on the hill sides, these lines would not have had the distinctness and regularity of a detrital shelf formed in the way we have suggested. Nor are there wanting indications of such subordinate lines, though they are in general very faint. In Glen Gluoy there are two such lines at about 150 and 200 feet above the parallel road. They are shown in a sketch by Captain WHITE, R.E. He says of them: "The two upper tracks, although well marked to the eye from this point of view and parallel to the lower one ('road' No. 1), show nothing when you reach the ground to indicate roads"—"an observation," adds Sir HENRY JAMES, "which is equally applicable to other places."*

These more or less indistinct lines and terraces have been particularly noticed by Mr. MILNE HOME and Dr. CHAMBERS.† They describe two shelves intermediate to "roads" 2 and 3, at three several places in Glen Roy, namely, on the front of Tombrahn, on the face of Ben Erin, and on the hill opposite Achavady farm. The higher one was 14 feet below the No. 2 shelf, and the other 36 feet lower. A second shelf was observed in Glen Gluoy, of the same character with No. 1 "road," but considerably fainter. This line was found to be 200 feet below the "road," and was traced for several miles in the upper part of Glen Gluoy.

* 'Notes on the Parallel Roads of Lochaber,' by Sir HENRY JAMES, p. 3 and pl. 2.

† 'Ancient Sea Margins,' p. 115.

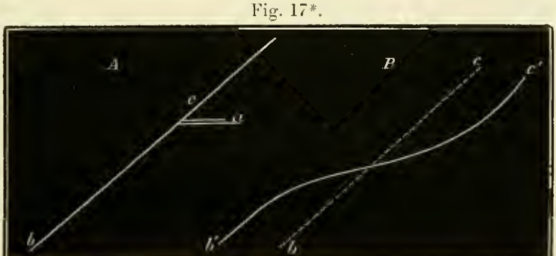
Chambers also refers to a well-marked assemblage of similar markings on the hollow face of Craig Dhu on the north side of the Spean, above "road" No. 4, two of them being at heights of 1,055 and 1,167 feet.* Corresponding with two higher ones at 1,337 and 1,495 feet, he found two bold lines on Ben Chlinaig, on the opposite side of the valley. Elsewhere, in Glen Spean, he noticed lines below "road" No. 4, one at 750 feet and the other at 661 feet. He considered that an unbroken series of lines exists from the present sea-level up to the highest of the "roads," but was of opinion that they are all the result of sea action, and that these glens were once arms of the sea.

Shelves have also been observed by Mr. Campbell on the south side of Loch Laggan, and he states that, in certain lights, several unnoticed water-lines become apparent in Glen Roy.†

Captain White's lines in Glen Gluoy may possibly indicate the height to which the water had risen before the rupture of the Turret barrier; and those of Chambers, in Glen Roy and Glen Gluoy, may indicate checks experienced by the water, owing to a variable resistance in the barriers as they yielded to the pressure of the lake waters. Weathering and vegetation have obscured and may have effaced many of these lines.

[Since the reading of this paper, my attention has been directed by a notice in the Min. Proc. Inst. C. E. (vol. lv., p. 339), to a memoir, bearing on this question, of M. René Lefebvre's, in the 'Annales des Ponts et Chaussées,' 5me. ser., tome xvi., 1879, p. 390, "Sur la Constitution des Terres, et sur les Accidents dans les Terrains Argileux." In this paper the author discusses the cause and effects of slips on slopes formed of argillaceous soils, and he shows that, in the instance of a slip of an embankment, fig. 17* A, the slope assumed is that given in fig. 17* B.

Fig. 17*.



c', b. Original slope of bank. c', b'. Slope of land after the slip.

The cases are not identical in origin, the cause of the slip in the original being due to a thin permeable seam at a, but the effects are, to a certain extent, analogous, inasmuch as the ledge c', b', formed by the slipped mass c, b, after heavy rains, is of similar form to that which we have shown would result from the slips on the slopes of Glen Roy, where they were due to the general permeation of the mass.

* Some of these higher horizontal or quasi-horizontal lines are shown in Captain White's sketches No. 3 and No. 4, but the lower ones there drawn are moraine mounds levelled by water action.

† *Op. cit.*, pp. 14, 15.

In a previous paper on the same subject, M. COMOY (tome x., 1875, p. 8) gives (p. 34) as an almost self-evident proposition, "Les terres disposées en talus commencent à glisser lorsque la force de cohesion qui les maintient sous une certaine inclinaison diminue *par une cause quelconque* et devient plus faible que l'action de la pesanteur. . . . La cause principale de l'alteration de la force de cohesion des terres est *la presence accidentelle de l'eau dans leur massif.*" The italics are mine.—J. P., July, 1879.]

§ 13. *The "Minor Barriers" on the Cols or Passes at the Head of the Glens.*

I use this term to denote those smaller masses of ice and moraine débris which, lodged on the cols during the extension of the great ice-sheet, survived the first effects of the thaw, whether in consequence of their higher level, or of favourable gathering grounds and thicker ice. To those larger accumulations of ice and moraine débris extending across valleys and blocking up the entrances of large glens, I restrict the term "main barriers."

There may have been a minor barrier on the col connecting Glen Gluoy with Glen Roy by way of Glen Turret, but the tributary glens are small, and in this case it is not essential. The one on the col connecting Glen Roy with Glen Spey is, on the contrary, necessary on our hypothesis, and can be accounted for by the number of large glens on either side of the col—glens which have their rise in mountains that attain the height of 2,889 to 3,700 feet.

Suppose, therefore, no barrier to have existed on the Turret Pass, and one lake to have at first extended through Glen Gluoy and Glen Roy. As the fall of the water-level would then, on the bursting of the common retaining barrier, take place simultaneously in both glens, the "roads" No. 1 in Glen Gluoy and No. 2 in Glen Roy would result from the same discharge; for the fall of the water, although arrested in Glen Gluoy, on reaching the level of the Turret Pass, at the level of the Gluoy "road," would continue in Glen Roy to the further extent of 21 feet, or to the level of the Roy and Spey Pass. If we may judge by Captain WHITE's faint upper water-lines in Glen Gluoy, the original level of this lake may have been 150 to 200 feet above that of these higher "roads:" so that when the Spey Pass barrier gave way, the sudden fall of the lake-level resulted in the formation of these "roads" (Nos. 1 and 2), in the same manner as the bursting of the Glen Glaster barrier gave rise to "road" No. 3.

As I have already pointed out, both passes exhibit the appearance as of the passage of a large and rapid body of water, and there is an absence of the more restricted and narrower water channels which would have resulted from long-continued river action, such as the ordinary drainage of these glens must have given rise to.

With regard to "road" No. 4, there are difficulties which I am unable to explain to my own satisfaction. The lower and latest lake, to which it is due, must at one time have extended throughout Glen Roy, and the whole of Strath Spean, as far as the pass of Makoul, where I presume it to have been blocked by a minor barrier, so that at first the level of the lake was considerably above that of the pass.

My hypothesis requires that "road" No. 4 should be formed simultaneously in Glen Roy and in Glen Spean, and for that purpose the removal of the main barrier at the entrance of Glen Roy previously to, or at the time of, the formation of that "road" is essential, as otherwise the "roads" in the glens would not have been on the same level. If the displacement of the barrier had taken place previously to the fall of the water, it could only have been that the waters in the Spean Valley, having yet no outlet, gradually accumulated until they reached the same level in both valleys. Then, on the gradual decay and waste of the main barrier, the waters of the two valleys intermingled in one sheet, so that when, later, the Makoul barrier burst, the fall of the united lakes would be simultaneous.

If, on the other hand, the Glen Roy main barrier gave way soon after the destruction of the Glen Glaster barrier, we may suppose that the sudden large accession of water to the Spean lake resulted in the immediate bursting of the Makoul barrier, when the fall of the two lakes would proceed in conjunction, until the level of the pass was reached, and "road" No. 4 projected simultaneously in Glen Spean and Glen Roy, with probably a slight break on the site of the barrier.

On the first supposition the barrier at Makoul should have exceeded 200 feet in height: on the second it need not have exceeded 80 to 100 feet. Around this pass the drainage of the mountains between Loch Laggan and Loch Ericht (a prolongation of the Ben Nevis range) centres, and consequently a large volume of ice must have issued from the glens or valleys of the Pattack and the Mashie. These streams, joining with the glacier coming from the Spean Valley, here met the ice of the valley of the Spey, together with that coming from an opposite direction down Glen Markie. All, therefore, tended to a large accumulation and remainder of ice at this particular spot, on the removal of which the lake was suddenly lowered to the level of No. 4 "road." CHAMBERS, like JAMIESON, speaks of this pass as confined by wall-like rocks which seem water-worn, and as "having the appearance of an ancient watercourse."*

The difficulty respecting the origin of No. 4 "road" is, however, no less on the other hypothesis, which requires first the pre-existence of the Spean lake, inasmuch as that valley is supposed to have received the overflow of the Glen Roy lake over Glen Glaster col, and secondly the subsequent extension of the Spean Valley waters into Glen Roy. In that case, the greater antiquity of "road" No. 4 in Glen Spean (for that greater age must have been equal to the time required for the formation of the second Glen Roy "road," No. 3, by slow wear and erosion) should show in some difference of form or dimensions of No. 4 road in the two glens; but there is none. Again, the removal of the Glen Roy barrier and the extension of the lake into the two valleys involves the continuity of "road" No. 4 from one valley to the other; whereas the line is interrupted in Glen Collarig, and on one side of Glen Roy (though,

* 'Ancient Sea Margins,' p. 112.

apparently, not on the other side), just where the barrier stood. This absence of the lines on the site of a barrier is to be noticed also on the sites of the presumed minor barriers in the passes of Glen Roy and Glen Glaster.

§ 14. *The "Main Barriers" at the Entrance of the Glens.*

The main barriers to Glen Gluoy, Glen Roy, and Glen Spean were, I consider, as before stated, mainly due to the circumstance of an accumulation of ice so excessive as to last for a certain time after the ice generally had greatly given way. This limits the time for the formation of the "roads," as such ice-barriers, under these conditions, could not have had a very long duration. The formation of the "roads" on the hypothesis advanced in this paper is not, however, dependent on great length of time.

Of the barrier to Glen Gluoy I am not able to speak further (ante, p. 683). With respect to the Glen Roy barrier, although it may have consisted chiefly of ice, it evidently was formed in considerable part of moraine detritus, brought on the one side by the glacier coming down Glen Roy, and on the other by the ice from the Ben Nevis range and the Spean Valley. Meeting here in opposition, not only were the ice-streams checked and heaped up, but the moraine detritus was also massed and spread over the bottom of the glen, forming a bed extending from a short distance beyond the entrance of Glen Glaster to and beyond Bohuntine. So important was this deposit of moraine matter, that the portion of it which remains, after the bursting of the barrier and the long-continued abrasion of the river, still forms a continuous mass 2 miles or more in length and from 50 to 200 feet or more thick, rising from the bed of the valley (which is, where the deposit is thickest, 350 feet above the sea) to the height of 700 to 750 feet on the slope of Bohuntine Hill, or to within 100 feet or less of the level of the lower "road" No. 4. On the opposite side of the river much less seems to remain. Considerable remnants of moraine detritus, overspread with a large amount of its water-worn and iron-stained débris, also extend to Auchaderry and Roy Bridge. The following is a section of the valley on the line of the barrier.

Fig. 18.

Diagram section across Glen Roy, 1 mile N. of Bohuntine: distance across on No. 2 line—1 mile nearly.
b. Moraine detritus and gravel. I am uncertain of its extent on the east side of the section.

Mr. Milne Home describes another important mass in Glen Collarig, where the other portion of the Glen Roy barrier is placed on the Ordnance map, but this I have not seen.

This moraine detritus is overlaid by a thick mass of loam and gravel, generally roughly stratified, but with some portions finely laminated, and showing in places reversed or contorted layers. The following is a section exposed on the right of the road, about a mile beyond Bohuntine, and about 650 feet above the sea-level. A short distance further the road rises to 752 feet, still on the same deposits.

Fig. 19.

Section transverse to Glen Roy and nearly opposite Glen Glaster.

a. Light coloured loam with seams of darker gravel, *a′*. *m*. Grey Moraine detritus or Till.

The loam, *a*, is full of slightly-worn angular and subangular fragments of mica-schist, with a proportion of well-worn and rounded pebbles. The upper part contains beds of subangular gravel, *a′*, often ferruginous, of the same materials, which at places have the appearance of having been thrown down and back by ice or water pressing on and moving over it rapidly, as might have been caused by the bursting of the Glen Roy barrier and the escape of the lake waters. Thence, to Achavady, these roughly-stratified beds of loam gravel and till attain a considerable thickness, dipping always towards the centre of valley ; while beyond this point the road descends, these deposits become less important, and the moraine detritus disappears or is hidden by the gravel which is spread over the bed of the valley.

Before reaching this place, however, several good sections of these deposits are met with : one in particular exposes them to a depth of from 100 to 150 feet. The upper 20 to 30 feet consist of the reconstructed moraine detritus, horizontally arranged by the action of water. The lower 80 to 100 feet consist of sloping moraine detritus somewhat roughly bedded. From the top of this bank there is a fine view up Glen Roy, while the height from which one looks down gives a vivid impression of the importance of the detrital bank beneath. A general idea of the structure of this bank is given in the following sketch, fig. 20. The thickness of the beds is only estimated.

Fig. 20.

Glen Roy from the detrital bank above Achavady, looking north.

a. Gravel of reconstructed moraine detritus . . . . 30 feet ?

m. Roughly bedded moraine detritus (its full depth is not shown) 100 ,, ?

The moraine detritus probably extends in patches higher up Glen Roy, but it is so covered by coarse gravel and rubble, which in some sections is from 15 to 20 feet thick, that it is rarely exposed. The section of the "road," fig. 13, shows, however, a mass of the moraine matter remaining on a ledge on the slope of the hills, and fig. 15 indicates also its existence at their base on the same east side of the valley.

The vast size of the glacier needed to block the entrance of the Spean Valley has always been felt to be a difficult problem. We have to imagine a barrier 4 miles long and having a height of not less than 900 feet above the sea-level; but it must be borne in mind that the bed of the Spean is here 200 feet above the sea, and that, at the distance of half a mile on either side, the ground is 500 feet high, and thence rises gradually to the height of 1,000 feet or more. The difficulty is much lessened if we consider the barrier to have been formed not only by a remnant of the old ice-sheet, but also by the detrital mass which forms Unachan Hill (rising to the height of 613 feet), and which is spread over some of the adjacent hills to the height of 800 feet or more, and extends also irregularly on the one side to the Great Glen and on the other to the flanks of Ben Nevis. The large quantity of this moraine detritus at the entrance of the Spean Valley, and on the flanks of the hills on either side, together with the extensive overlying beds of rolled gravel and sand formed of its wrecked portions, and spreading thence to the Lochy and Loch Linnhe,* renders it also

* CHAMBERS speaks of it as a mass of gravel 11 miles long by perhaps 2 broad.

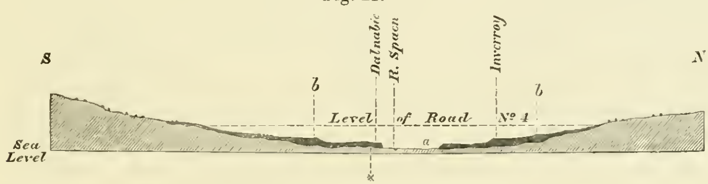
tolerably certain that, before the rupture of the barrier, the quantity of moraine detritus here was much greater than now. The accumulation of this detritus, like that of the ice, resulted from the block of the many large glaciers at this point.

The existing shape of Unachan Hill does not represent that of the original mass of moraine detritus. This was more transverse to the valley, and the present form is due to the scour of the water as it escaped seaward in the direction of Loch Linnhe on the bursting of the barrier, and to subsequent denudation. I saw the moraine débris only near its base, but I am confirmed in my opinion by the observations of Mr. Campbell, who remarks that he found the hill to be "made chiefly of deep moraine stuff with many large polished boulders in it, covered with rolled gravel and peat where I could get at it."* (See Map, Plate 46.)

I therefore think it probable that this barrier, like the one at the entrance of Glen Roy, although formed chiefly of ice, was largely supplemented and strengthened by unstratified argillaceous moraine detritus. I also think that this detritus extended within the barrier and there reduced the depth of the valley; for the several terraces, such as those of Inverroy and the opposite ones of Inch, have a foundation of moraine débris with a capping of drift gravel, resulting apparently from the levelling caused by the escaping waters on the rupture of the barrier. As the waters fell lower they, in combination with subsequent river action, cut out deeper channels through the moraine detritus, leaving its escarped flanks rising on both sides of the valley.

The following section gives generally the position of these detrital terraces between Roy Bridge and Spean Bridge. This and the following two sections (figs. 22, 23) have the same horizontal and vertical scale of 1 inch to the mile.

Fig. 21.



Section across the Spean at Inverroy near Roy Bridge. *a*. River gravel.
b. Moraine detritus and gravel (represented somewhat too thick). * Ice-worn surface of rock.

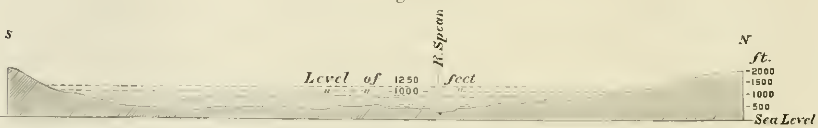
This section also shows the depth the lake—level of "road" No. 4—would have had 1 mile inside the barrier; while figs. 22 and 23 give sections of the valley at the line where the barrier is placed by the Ordnance Survey, and again 1 mile beyond, where the detrital mass of Unachan Hill intervenes.

In these sections the height of the ground is represented in relation to the present sea-level, but as we have shown reason to conclude that the lakes were formed during

* *Op. cit.*, p. 20.

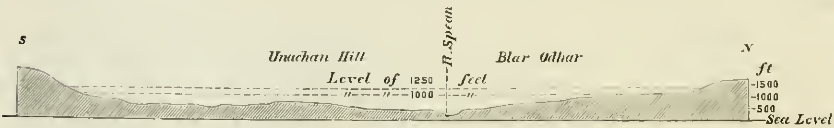
the period of submergence which succeeded the great glaciation, the question arises what was the height at which the sea stood in this area at the time when the Lochaber lakes existed ?

Fig. 22.



Section of the Spean Valley adjacent to the line of barrier.

Fig. 23.



Section 1 mile further west.

The levels of 1,000 feet or of 1,250 feet show the height needed for the barrier. The lake is represented by the broken lines in fig. 22.

As I see no sufficient grounds for attributing the origin of the erratic blocks and detrital terraces at high levels to marine action, and as it is possible to account for many of even the lower terraces in Strath Spean by causes in connexion with the Spean glacier lake, there seems to me no reason why the submergence in Lochaber should have exceeded 300 to 500 feet. In the valley of the Spean the terraces are of very variable height, ranging, according to CHAMBERS, in the lower part of the valley, from 325 feet at Tiendrish, 283 feet at Inverroy, and 345 feet at Inch, to, higher up the valley, 392 feet at Auchaderry, 446 feet at Monessie, and 627 feet on the side of Craig Dhu. Nor do the levels of the terraces on opposite sides correspond. These irregularities of horizon are not in accordance with lines of permanent water level either of lake or sea. Nevertheless some of the terraces described adjacent to this district by CHAMBERS below the level of 300 to 400 feet, may possibly be due to marine action.*

In the absence of more positive data, it is, however, with some hesitation that I express an opinion that whatever may have been the height of the sea in other areas, it stood during the period of maximum submergence in this particular district at not more than about 500 feet, if so much, above its present level.

* He states there is a terrace 325 feet high at Fort William, which corresponds with the height of the one at Tiendrish, while around the first place he mentions nine others below that level (the lowest being 32 feet), of which six, between 288 and 96 feet, correspond very closely with others at Inverness and Fort Augustus [and] on the Morayshire coast. The coincidence of these is sufficiently marked to render it possible that they may all be referable to a common cause such as a sea-level, as the land rose again after the submergence. Allowing, again, for different degrees of elevation at distant places, might not some of these last terraces correspond with the higher beaches of Jura and adjacent islands?

The great beds of rolled pebbles at the junction of the Lochy and Loch Linnhe, and extending thence to Gavilochy where they reach a height of 100 feet, alone have completely the appearance of the wear and levelling caused by long-continued marine action.

§ 15. *Irregularities in the Levels of the "Roads."*

The "roads" have always been spoken of as though they were, and to all appearances when standing on them they look to be, so perfectly horizontal that not until the foregoing pages were written was I led to question the point. The excellent 1-inch maps of the Ordnance Survey, shaded or with contour lines, are so complete and convenient, that I had not thought it necessary to use the 6-inch maps. On recently referring to these latter, I unexpectedly find that the figures there given of the height of the "roads" at different places show differences * of level, which though comparatively small, are nevertheless sufficient in number and in frequency as to be incompatible with water-levels formed by the shore-lines of either a sea or a lake.

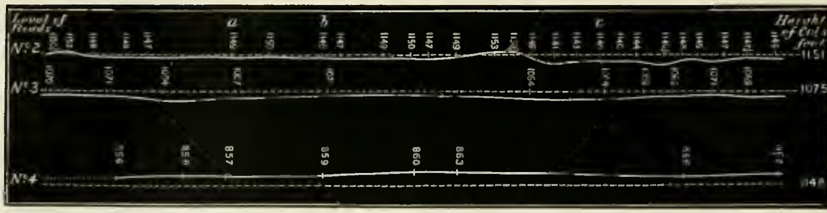
Instead of a perfectly horizontal line, the "roads" are really slightly waved, the difference between the highest and the lowest points being, in the four "roads," taken in descending order, 15, 11, 15, and 12 feet; and it is to be remarked that, while the level of the higher three "roads" is in most instances below that of the several cols, that of the lower "road" is in all instances above it. These differences are shown in the following table :—

"Road."	Height of col.	Extreme differences of level between the cols and the "roads."		Total difference in the level of the "roads."
	feet.	feet.	feet.	feet.
No. 1. Glen Gluoy	1172	+ 1	−14	15
,, 2. Glen Roy	1151	+ 4	− 7	11
,, 3. Glen Roy	1075	+ 2	−13	15
,, 4. Glen Roy }	848	+14	+ 2	12
,, ,, Glen Spean }		+10	+ 2	8

The variations of level form separate curves for each "road," and do not constitute one common to all, so that they cannot be referred to subsequent movements of the ground, as these would have affected all the "roads" in the same degree. Besides this want of correspondence between the curves on the same hill side, there is a similar want of correspondence in the levels of the "roads" on the opposite sides of the valley. The character of these variations, and the relation of the several curves with a horizontal plane are shown in the following diagram (fig. 24) of the curves formed by a point taken in the centre of the "roads" on the west side of Glen Roy from above Achavady to near Dalriach, a distance of 4 miles.

* The lowest and highest level of each "road" is given by Sir H. JAMES, but without comment. He adopted Mr. JAMIESON's views —*Op. cit.*, p. 2.

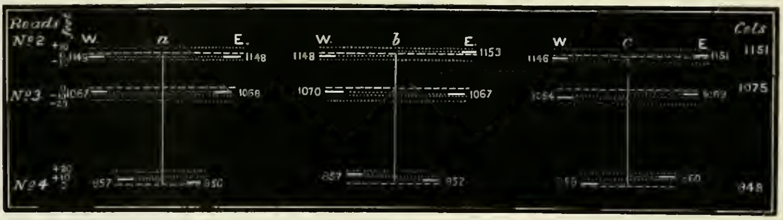
Fig. 24.



Levels of the "roads" longitudinal* with the valley, west side, in a length of 4 miles.
Vertical scale of levels, $\frac{1}{10}$th inch = 15 feet.

Fig. 25 exhibits the difference of level of corresponding "roads" on the opposite sides of the valley at the three points marked *a*, *b*, *c*, in fig. 24.

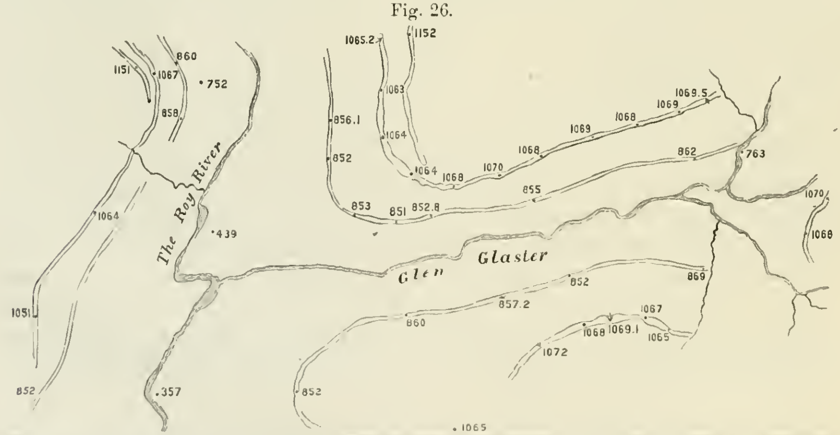
Fig. 25.



Levels of the "roads" transverse to the valley. 0 marks the level of the cols, and — that of the "roads."

These variations of level extend the whole length of the "roads." The following sketch-map, reduced from the 6-inch Ordnance map, shows the difference in the height of the "roads" lower down the valley, and in its lateral Glen Glaster.

Fig. 26.



* Only those levels are given where the dot shows the observation to have been taken in the centre of the "road." In fig. 26 too great unevenness of outline is given to the "roads."

Irregularities of level, small as these are, could not exist in the shore-lines of quiet and narrow lakes. If the differences had been caused by subsequent movements of elevation or depression, all the "roads" would have been affected alike and the curves would have been similar and parallel, and not discordant. Therefore the variations could only be due to a cause influencing each case separately and independently, but in each case, nevertheless, the similarity of the effects indicates a cause of the same nature; and if of the same nature, the conditions under which "road" No. 3 was formed will be equally those which governed the formation of the other three "roads," and the explanation suited for that one will be applicable to all.

That explanation was, that the rapid fall of the lake on the bursting of the minor barrier on the col led to a sliding or slipping down of the detritus on the slopes of the hill,* which continued until checked by the water coming again to rest on reaching the col level. A perfect horizontality of the "roads" is indeed hardly compatible with this hypothesis, as the momentum of the falling mass of detritus must have been greater or less according to the slope of the ground, and, slight variations of slope being frequent, small irregularities of level would naturally follow.

There are, it is true, two other ways in which some variation of level might, if within certain limits, be accounted for: the one by a subsequent irregular subaerial fall of débris from the slope above, and the other from the circumstance that as the observations are taken in the centre of the "roads,"† the inclination of which varies, so the height of the centre in relation to the inside edge of the "road" would vary accordingly.

But there is nothing to connect the irregularity of the "roads" with irregular falls of débris which would be apparent by the greater talus at the foot of the slope; and the actual differences of level at the central points are too great to come within the limits of variation that arise from the differences of the angle of inclination. Taking the inclinations, apart from a few very exceptional cases, to vary between 5° to 25°, and the width of "road" to average about 50 feet, the difference arising from this range of variation in the angles would not exceed 8 or 9 feet, and, looking at the inclines more commonly met with, the difference would more generally be confined within the limits of 2 to 3 feet. This will therefore hardly account for "roads" Nos. 1, 2, and 3 being so often 10 to 14 feet below the level of the cols; while in those cases where the "roads" are above the cols, which they occasionally are to the extent of 4 feet, the difference due to the foregoing cause must be taken in addition to, instead of in deduction of, the apparent difference of level. No. 4 "road," also is always from 2 to 14 feet *above*, and is never *below* the level of the Pass of Makoul.

* Slides now occasionally take place after heavy rains. I saw one which had occurred a short time before my visit, on the side of the hill beyond Dalriach, on the east side of the glen. As well as I could judge at a distance, the fall had extended for a length of about 100 feet, and had left the rock bare.

† The "roads" have no doubt been raised generally by subaerial débris, while the cols may also have been raised a few feet by the accumulation of soil since the lake waters passed over them.

It would appear therefore from the want of agreement between the levels of the "roads" and of the cols, and from the want of horizontality in the lines of the "roads" that they cannot be referred to the definite zones of an established and uniform water-level, regulated by the height of the cols, and combined with long continued shore action. The facts admit however of ready explanation on the principle that the momentum of the sliding mass of detritus, varying necessarily according to the angle of slope, would, in those cases where the slopes were greatest—other conditions being alike—carry that body *below* the surface of the water; while in other cases where the slopes were less, it proved insufficient to effect the descent quite to that level. Or the difference in the slide might have been due to the lesser rapidity with which the level of the lake fell. Thus the height of "road" No. 4, which is always *above* the level of the escape-col at Makoul, may have arisen from the slopes of the hill at that level being, on the whole, somewhat less steep than at the higher "roads;" or the main cause may have been the slower discharge of the water arising from the vastly greater size of the lake, while the pass was no wider, if so wide.

The diminished momentum on lesser slopes may also be one cause why the "roads," in some places where the gradients are much smaller, almost disappear, which would not be the case to the same extent if the "roads" had been formed by long continued shore action.

Not only therefore is the variable inclination and want of horizontality of the "roads" compatible with the hypothesis of detritus sliding down a slope, but this seems to me the only hypothesis on which the differences of level between the cols and the "roads," together with the curves in the lines of the latter, can be explained.

§ 16. *Further considerations in connexion with the Great Ice-sheet, suggested by the Local Phenomena of Lochaber.*

The Till of Scotland has been described as the product of the *moraine profonde* of the old glaciers. In the sense attaching to this term in existing glaciers this use of it is likely to lead to misconception. The original definition was intended to denote one form of moraine in contradistinction to the three forms of lateral, medial, and terminal moraines; while in the sense in which it has sometimes been used by geologists it would include the product of these several moraines and perhaps more.

The *moraine profonde* (*couche de boue*) of AGASSIZ, generally, is that layer of rock fragments, pebbles, and rock powder which is held in the ice at the bottom of a glacier and spread in places over its bed. It is rarely more than a few inches or a few feet thick, and the rocky bed is more often bare. DOLFUSS-AUSSET describes it to be "materials buried under the glacier," including however in that definition those which have fallen in front in the course of ablation.* HOGARD says "the layer of mud, sand, pebbles, and blocks beneath the glacier constitutes the *moraine profonde* which forms almost

* 'Matériaux pour l'Étude des Glaciers,' vol. v., p. 415.

always the base on which the frontal moraine reposes."* Elsewhere he speaks of the *moraine profonde* as "the blocks, pebbles, and detritus held between the ice and its bed."† These definitions are conflicting, and although it is evident that geologists have used the term in a modified sense, and that an ice-sheet acts under different conditions to an ordinary glacier, I think it better not to use a term in a so much wider significance than allowed by its author or by glacialists generally. The terms simply of "moraine detritus" or "sub-glacial detritus" are not open to this objection.

It is only when the glaciers descend into wider valleys with small gradients and are able to expand laterally that they cease to plough their bed, and spread over detrital beds instead of uprooting them. But when from any cause the glacier again undergoes lateral compression, owing to another contraction of the channel or to the confluence of other glaciers, the abrading and propelling power recommences. Consequently the ice may in some places over-ride the terminal moraine, or it may in others force it to higher levels, until stopped by interferences presently to be noticed, pounding and grinding the ground in its furthur travel, and leaving as the product of this mixed origin the great body of unfossiliferous and unstratified Till.‡

From this mode of formation there would necessarily result that irregular distribution of the Till exhibited in hilly and mountainous countries, and those lodgments of it in exceptional positions which arose from the antagonism of the extending glaciers, and from the blocks and heaping up of the ice described in § 8. In such cases the moraine detritus likewise would be stopt and piled up in some places, and spread out in others, whether in valleys or on slopes, at the mouth of glens or on mountain passes. In this way it was, I imagine, deposited in the broad entrance of the Spean Valley, in the narrow gorge of the Roy, on the slopes of Creag Dhu, and on the many hills elsewhere in Scotland.

It must also have often happened during the growth of the ice-sheet that valleys were crossed by glaciers descending from lateral ravines, thereby stopping the drainage and giving rise to basins, which for a time received the waters and débris carried down by the river and tributary streams. There would thus be formed lake-basins with sand and shingle spread over their bed, and extending to the Till of the blockading glaciers; and as the ice-streams closed in, their moraines, pushed forward and over the sand and shingle beds, would overlap the lacustrine beds. This process might be repeated for a time, so that when ultimately, owing to the increasing intensity of the cold, the ice-streams passed over and buried the lake basin, we should have local stratified deposits of freshwater sand and gravel embedded in and overlaid by the unstratified masses of glacier Till. Although the increasing cold would in most cases so strengthen the ice barriers that they became permanently established, there must have been cases where the volume of the river was for a time too great for the barriers to

* 'Matériaux pour l'Étude des Glaciers,' vol. v., p. 201.

† Ibid., p. 219.

‡ See also on this subject the 'Great Ice Age,' 2nd edit., chaps. vi. and vii.

resist, and when they gave way there would be deposited lower down the valley, or in the next basin, great beds of débris and shingle carried down by these *débâcles*, to be in their turn buried at a later period; for eventually all the watercourses were stopped, and ice overspread the whole land.

Admitting, therefore, under certain modifications, with most of the Scotch geologists that we have in the Till (and its associated beds of gravel and sand) the sub-glacial product of the great ice-sheet, we have further to consider the detritus scattered on the surface of that great mass of ice and distributed by the torrents and floods to which it gave rise in its decay. For this purpose the evidence furnished by the Lochaber lakes is of singular value, for it is evident that what we see there is only part of a great general phenomenon extending in mountainous districts as far as the ice-sheet itself extended.

Instances are not wanting of traces of Parallel Roads in other valleys, but they are so faint that they often escape notice. Besides the special glacial conditions, a sufficient slope, and a sufficient covering on the slopes of peculiar detrital débris, are essential for the perfect development of the shelves. Often apparent at a distance, they fade on approach. This is not surprising when, as occasionally happens in Glen Roy, the inclination of the "roads" so nearly approaches the angle of hill-side slope. It is possible that some of the many higher lines and shelves noticed elsewhere by CHAMBERS may be referable to this class of phenomena; but besides these more general cases,* DARWIN mentions a particular instance in Glen Kilfinnin—a glen which runs into the Great Glen 8 miles north of Glen Gluoy.† This Glen Kilfinnin "road" is about 40 feet above the upper "road" of Glen Roy, and extends about 2 miles on the face of the surrounding mountains. Mr. MILNE HOME has also recently directed attention to distinct traces of similar lines, but having apparently a wider range, in a glen on the opposite side of the Caledonian Valley. These lines which are near the head of Glen Doe, form four horizontal terraces, the highest being about 985 feet above the sea, and the lowest about 895 feet.‡

Although in an ice-sheet formed of confluent glaciers from converging glens and valleys, and of opposing glaciers from other distinct mountain and valley systems, the ice may often have been heaped up and have formed barrier-dams, yet without the secondary conditions just named, and without regulating cols, no "roads" could have been formed. At the same time, from the frequent rough and hummocky character of the ice produced by these causes, its surface could not fail to have been covered, on the first melting of the ice and snow, with pools and tarns or small lakes, such as, at the present day, are frequent where, as before described (p. 694), the lower part of a glacier occupies a warm valley with a small gradient.

* 'Old Sea Margins,' pp. 119–124.

† Phil. Trans. for 1839, p. 42.

‡ Proc. Roy. Soc. Edinb., Session 1877–78, p. 23.

An analogous effect must have resulted from the gradual melting of the great ice-sheet, only that instead of being dependent solely on the seasons and recurrent, it was an ever-increasing quantity in consequence of the continuous rise in the annual temperature; and the waters accumulated in larger and more frequent bodies in consequence of the vast extent of the ice-field and the greater compactness of the ice.

While pools and lakes were formed in the depressions on the ice, rivulets and streams on the hill sides scattered sand and gravel on its surface. As the barrier ridges melted or burst, the waters escaped to lower levels, carrying with them, on the ice,* a large portion of this detritus; while at times the circumference of the lakes increased until they extended to the hill-sides. Formed at all levels up to 2,000 feet or more, these glacier-lake waters in descending to lower levels met and combined with other bodies of water, and the transporting forces increased in power till the last stage was reached and open channels found in the distant plains—the waters leaving as marks of their passage down the valleys, and according to the distance from the point of outburst, here great banks of gravel, and there deep beds of sand. Other portions of the glacier débris, where the ice became less compact, falling into crevasses or pipes, would be carried by sub-glacier torrents, and deposited along the same lower valley channels, or swept out to the terminal estuary.

To these bodies of water pent-up at all elevations on the decaying ice, and to these tributary streams carrying down sand and gravel and often casting it in marginal lines, may be due many of those numerous terraces and indistinct water-lines observed on some of the Scottish hills; while as other portions of the sand and gravel were swept down into the lower levels,—flooded by these great bodies of water, or into the sea which we have seen reason to believe then stood higher than now,—the foundations were established of those detrital deltas, terraces, and escars, which constitute so marked a feature in the valleys and plains of Scotland.

Besides these forms of drift appertaining to the old ice-sheet, there is the débris that would be left *in situ* on the ground, when the ice melted away. This would consist of dirt and rock fragments and boulders, embedded in and scattered on the ice, of remnants of moraines, and of small cones of dejection dotted on its sides, or formed into lines on its margin, by the streams and rivulets of the surrounding hills.

Thus we have, on various levels, the transported débris and boulders left by the great ice-sheet, together with the angular local débris produced by the intense cold; while, commencing in the higher levels, but with a development increasing as we descend to lower levels, we have as the result of the action of the rivulets, the streams, the glacial-water floods, and the rivers, much of this débris worn and mixed up into an undistinguishable mass of gravel and sand, overlying, wherever they remain, the heaps of sub-glacial moraine detritus left beneath on the retreat of the great ice-sheet.

* Streams flowing on the surface of glaciers are found to have a similar power of wear and forming pebbles as streams on a land surface.

But however wide the bearing of the conditions which existed in Lochaber may be upon the complex general phenomena of the drift deposits of Scotland, it is too small a standpoint from which to discuss that great question. I have therefore here restricted myself mainly to a general consideration of those problems that hinge more especially upon the remarkable conditions which, while they are wide spread, show themselves with exceptional distinctness in the Lochaber district.*

§ 17. *Conclusions.*

The general conclusions I draw from the phenomena in Lochaber and surrounding districts are—

1st. That at the period of the first great glaciation of Scotland the ice-sheet in Lochaber attained a thickness of not less than 2,000 to 2,500 feet, and that, in consequence of the peculiar physiographical conditions of the district, the large ice-streams from Ben Nevis so clashed with others in the Spean and Caledonian Valleys that a block ensued, which led to an exceptional heaping up and accumulation of the ice in front of Glen Spean, Glen Roy, and Glen Gluoy.

2nd. In consequence of the lowering and partial submergence of the land, and its conversion from a continental area to an archipelago, combined with some other more general cause, an amelioration of the climate took place, attended by a gradual melting of the ice-sheet. The snow and ice wasted from the valleys and from the lower mountain summits; and in the absence of any established water-courses, the hollows and depressions in the ice were converted into pools and tarns, until the continued liquefaction opened out surface channels or fissures by which the water could ultimately escape.

3rd. That pending the establishment of natural lines of drainage, and in presence, at places, of unusual obstruction, the water accumulated in some valleys in larger bodies or lakes ; and if, in such cases, the mouth of the valley being closed by ice-barriers, other lower channels of escape, such as cols or passes communicating with adjacent open glens or valleys, presented themselves, the water overflowed through those channels as soon as it rose to the height of those cols or passes. Or should the cols have been also barred by ice, that ice would give way as soon as the increasing height of the water gave sufficient pressure, or led to an overflow. When this happened, the water would at once fall to the fixed level regulated by the col, and a definite line of water-level would be established, which would continue as long as the main barrier at the entrance of the valley lasted. If, however, this main barrier gave way before the pent-up waters found an escape by the pass, then, in the absence of any other outflow, as the lake would be always filling and never remain long at the same level, no permanent line of water-level could be established, and thus no record, such as we have in Lochaber, need have been left of the presence of such bodies of water.

* See on this subject 'The Last Stages of the Glacial Period in North Britain,' *cit. ante.*

4th. In the Lochaber district, while the exceptional accumulation of ice in the Spean Valley heavily barred the entrance of the glens on the north side of that valley, the passes at the head of the glens were also blocked by smaller remnants of the great ice-sheet; and the formation of the detrital shelves or terraces is due to the sudden bursting of these minor barriers, when the waters of the lake were discharged with great rapidity until they fell to the level of the col. Under these circumstances the mass of loose débris covering the hill-sides gave way and slid after the retreating waters, until stayed with greater or lesser abruptness, according to the angle of slope and the volume of the mass, on the discharge ceasing and the waters coming to rest. The shelves so formed, modified slightly by subsequent subaerial action, constitute the "roads."

5th. The moraine or sub-glacial detritus, in places where the glaciers clashed and their progress consequently became checked or delayed, tended also to accumulate or heap up, and, in this way, added in the Lochaber glens to the strength and permanence of the ice-barriers.

6th. While the moraine detritus was irregularly distributed under the ice, or massed in particular places, the débris projected on the surface of the ice-sheet and contained in its body was either, as the result of the great floods consequent upon the bursting of pool- and lake-barriers, carried successively to lower levels, leaving here and there banks of sand and gravel at various heights on the hill-sides, or else was left *in situ* on the liquefaction of the thick mantle of ice. These destructive floods, combined with the unceasing river inundations due to the same general thaw of the great ice-sheet, carried down and spread out in the valleys and plains the great beds of gravel and sand which, with the modifications since brought about by subsequent continued fluviatile action,* have given rise to various forms of escars, terraces, and other less defined accumulations of these detrital materials.

Explanation of Plate.

The topographical details and the range of the parallel roads are reduced from the shaded one-inch Ordnance Map. The probable positions of the Spean Valley and Glen Roy barriers are on the same authority. That of Glen Gluoy is conjectural on the part of the author. The heights are taken from the one-inch contour map of the Ordnance Survey.

In the names of places the spelling of the Survey is usually followed; but a few other names, commonly used by previous observers, have been retained. The direction

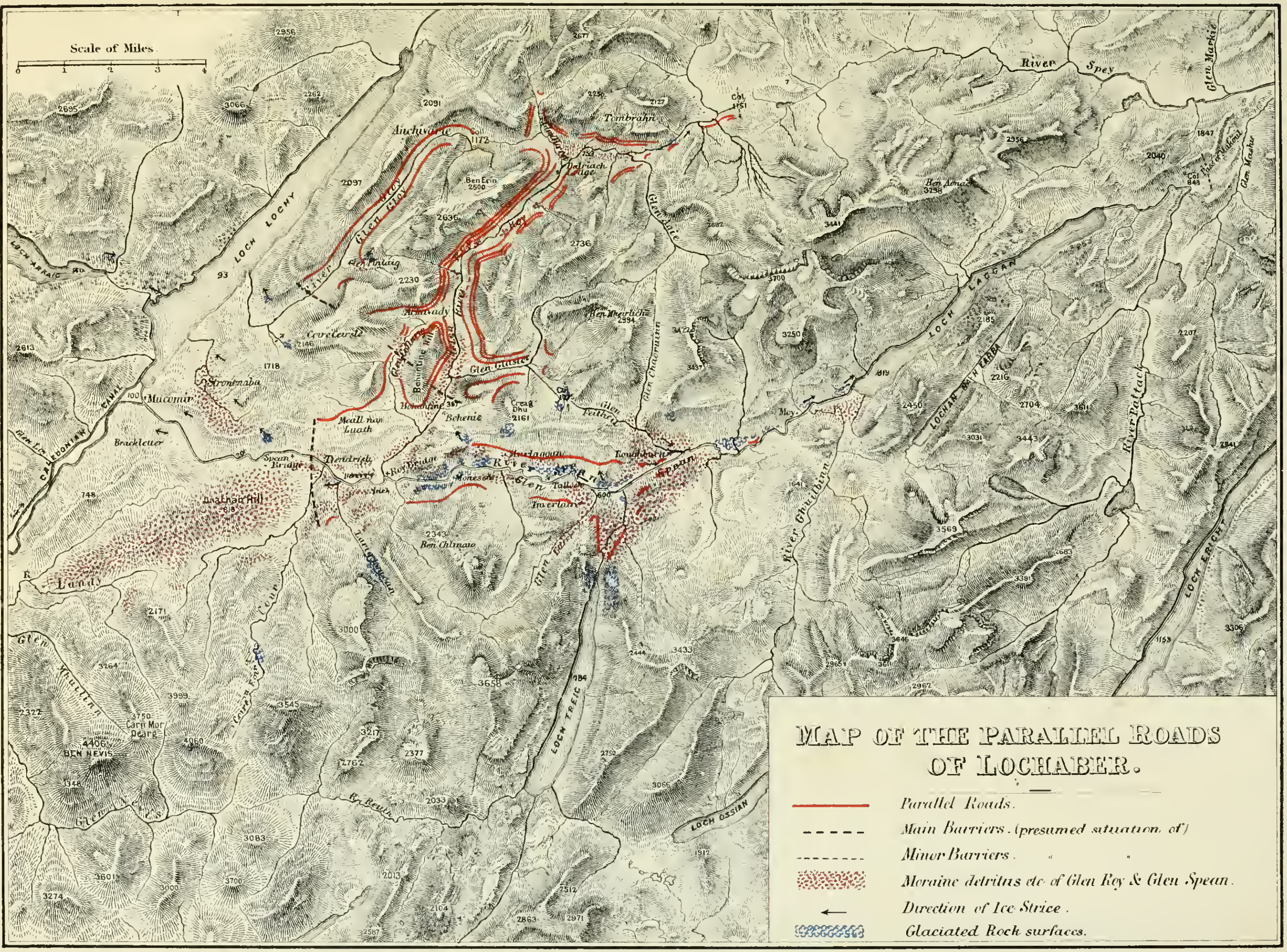
* The terraces and loose deposits due to this cause in the south of England and north of France will be found described in a former paper by the author—Phil. Trans. for 1864, p. 247.

of the ice-striæ and the position of the glaciated surfaces are mostly taken from previous memoirs, with few additions by the author; but the bearings of the former are given in most cases in conformity with his own views.

The distribution of the moraine detritus is shown only in the area visited by the author, and the map gives therefore a very partial indication of its extent. It will need a detailed survey to give a complete view of its distribution. West of Spean Bridge, also, it is only laid down very generally, without pretending to exact definition, the object being merely to show its large accumulation outside the barrier on the site of the old ice-dam.

The size of the several lakes may easily be estimated by prolonging the lines of the "Parallel Roads" from the main barriers to the coll or pass at the head of each respective glen or valley.

MAP 1.


MAP OF THE PARALLEL ROADS
OF LOCHABER.
Parallel Roads.
Main Barriers. (presumed situation of)
Minor Barriers.
Moraine detritus etc of Glen Roy & Glen Spean.
Direction of Ice Striæ.
Glaciated Rock surfaces.
Scale of Miles
0
1
2
3
4
LOCH LOCHY
LOCH LAGGAN
LOCH TREIG
LOCH OSSIAN
LOCH ERICHT
River Spey
Glen Markie
River Pattack
River Gulbin
Glen Spean
Glen Roy
Glen Gluoy
Glen Glaster
Glen Turret
Ben Nevis
4406
Fort William
Bracklettir
Mucomir
Tombrahn
Ben Erin
2500
Lochan na h Earba
Caledonian Canal
Lundy
River Spean